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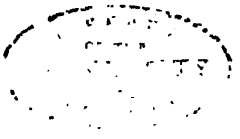

ROCK GYPSUM CONTAINING SELENITE CRYSTALS.

THE UNIVERSITY

GEOLOGICAL SURVEY

OF

KANSAS.

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OF THE UNIVERSITY OF KANSAS, AS AUTHORIZED
BY SPECIAL LEGISLATION.

VOL. V.

SPECIAL REPORT ON GYPSUM AND GYPSUM CEMENT PLASTERS.

BY

G. P. GRIMSLEY AND E. H. S. BAILEY,

UNDER THE DIRECTION AND WITH THE
ASSISTANCE OF

ERASMUS HAWORTH.

(Distributions of Reports made from the University, Lawrence, Kan.)

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Dr. F. H. Snow, Chancellor of the University of Kansas:

SIR—I have the honor to submit to you herewith for your approval a special report on Gypsum and Gypsum Cement Plasters, which will constitute Volume V of the reports of the University Geological Survey of Kansas. This report has been prepared principally by Prof. G. P. Grimsley, to whose paper Prof. E. H. S. Bailey, of the University, has added a chapter on the Chemistry of Gypsum and Gypsum Cement Plasters.

It was more than three years ago that Professor Grimsley was invited to make a special study of the Kansas gypsum under the general supervision of the Department of Physical Geology and Mineralogy of the University of Kansas. For three successive summers he devoted many weeks to field-work, examining in every way known to the geologist the various localities connected with the subject in hand. I am sure that the public in general will agree with me that it was a fortunate event in the history of the material development of our state which brought him in touch with our Geological Survey. The material used by Professor Bailey in the various analyses reported on by him was largely gathered by Professor Grimsley, but a part of the chemical work was done by Professor Bailey entirely independent; in fact, portions of it were accomplished before the University Geological Survey was organized.

My own connection with the report has been general rather than specific, being that of an adviser rather than a worker, and I have only occasionally made additions or modifications to the paper submitted by Professor Grimsley. However, I took immediate charge of the preparation of the illustrations, the drawings for which were made by Mrs. Haworth.

Yours most respectfully,

ERASMUS HAWORTH.

DEPARTMENT OF PHYSICAL GEOLOGY AND MINERALOGY,
UNIVERSITY OF KANSAS, December 15, 1898.

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INTRODUCTION.

BY ERASMUS HAWORTH.

THIS report on Gypsum and Gypsum Cement Plasters is the second special report issued by the University Geological Survey of Kansas which has a direct bearing on the mineral resources of our state, the former being the special report on coal, constituting Volume III of our Survey series. While many interesting and profound theoretical questions are touched upon here and there throughout the report it has constantly been endeavored to make it as intensely practical as possible, believing that there is no necessary incompatibility between the strictly theoretic and scientific and the economic problems connected with the geology of any region. Kansas has such unlimited quantities of gypsum occurring with such a wide geographic range, in such a great variety of forms, and under so many different geological conditions that it affords unusual opportunities for profound investigations along strictly theoretical lines. The field was therefore an enticing one, a field which would have been entered by many different individuals had opportunity been afforded.

Again, the economic importance of these same gypsum deposits is so great that it takes no prophetic mind to see in them for the future one of the greatest natural resources within the whole domain of our state. Everything indicates that the demand for gypsum and the various products manufactured from it will steadily increase rather than decrease. It is now generally admitted that gypsum cement plaster in its various forms is rapidly replacing almost all other kinds of plaster formerly used as constructive materials. Its increased production during the last decade is little short of marvelous, portending for the future a still greater increase, particularly should the revival of business now assured include a great extension of building and other constructional activity.

It is further probable, it would seem, that within the near

future the agriculturist will find it greatly to his interest to use crushed gypsum extensively as a fertilizer. At the present time, so far as is known, not a single farmer in the whole state has ever tried, to any considerable extent, its application to see whether or not it would materially increase his crop production. It is earnestly hoped that the extended and able discussion of the use of gypsum as a fertilizer given by Professor Grimsley will stimulate Kansas farmers to experimenting on different kinds of soils and on different crops to determine whether they may not be able greatly to increase the productiveness of their farms, and at the same time increase the market for one of the staple Kansas mineral products. That chapter particularly is earnestly commended to the careful attention of the great class of our citizenship, the Kansas farmers.

It is not believed by the writer that the present methods of manufacturing plaster from the different grades of gypsum are entirely what they should be. The future certainly will develop material improvements. The manufacturing process is so simple and the chemical changes to be accomplished are so few that it would certainly seem more refined methods of calcining the raw gypsum should be invented. The old-fashioned kettle with the ponderous agitating machinery connected therewith is not in good keeping with the modern advancements in the mechanic arts.

Since the gypsum earth plasters have been proved to be more desirable for some purposes than the purer plaster of Paris made from the gypsum rock, apparently it should not be a difficult task to imitate nature in the production of proper mixtures of pure gypsum with earthy materials to produce a plaster similar in every way to that made from the gypsum earth. It would seem that the problem is less difficult than that long ago solved for the manufacture of Portland cement.

Could a few improvements as above outlined be put into operation, and could the great abundance of cheap fuel in the southeastern part of our state be brought in touch with the vast gypsum deposits in the gypsum area, Kansas could supply the markets with the different gypsum plasters for the whole

Mississippi valley for thousands of years. It is not an idle dream that the proverbial American ingenuity and business enterprise will, in some way, in the near future combine these various factors of wealth in such a way that our gypsum will become one of our principal sources of revenue.

The general discussions given by Professor Grimsley and Professor Bailey are so complete in their scope and in details that little need be added from any other source. It might be well, however, to give the reader a sort of bird's-eye view of the geologic conditions in Kansas in order that he may the more readily orient himself properly while reading the more detailed accounts of the geology given by Professor Grimsley in chapter III.

GEOLOGY OF GYPSUM.

The student of geology is more liable to err by entertaining too contracted a view of geologic conditions than by one of too wide an expanse. One cannot well consider the great geologic conditions surrounding the formation of the Kansas gypsum deposits without at the same time carrying his observations both north and south beyond the limits of our state. The series of conditions which produced gypsum in Kansas were extended in both these directions throughout a long period of geologic time, with the result that similar gypsum deposits were formed in many other places.

Neither is the geologic age of a formation any indication of the probability of its carrying gypsum. The gypsum in some parts of America is Silurian in age. Elsewhere it occurs in the Coal Measures, at least to a limited extent. The lowermost part of the Permian which immediately overlies the Coal Measures contains the lowest beds of gypsum in Kansas. From here upward, through almost every distinct formation in the Permian, gypsum occurs in our state, while the Permian of Texas and the Cretaceous of Iowa have large quantities of it. One who is searching for gypsum, therefore, should heed indications favorable for gypsum formation rather than be looking for any particular geologic age, simply because elsewhere in America or in the world gypsum has occurred in that age.

At the close of Coal Measure time it seems that the greater part of the eastern half of the North American continent existed as dry land, with considerable portions of the great west also above ocean water. This left a great arm of the ocean extending north and south from the Gulf of Mexico to the Arctic Ocean, covering the territory now occupied by the western part of Texas, Indian Territory, Kansas, Nebraska and the Dakotas, and the eastern part of New Mexico, Colorado, Wyoming, and similarly situated portions of British Columbia.

The development of the continent throughout former periods of geologic time had, in the main, been a progressive one, so that by the close of each time period a new portion of dry land had been added to the young continent, continuously making it larger. At one time the western coast of the continent was near the southeast part of the state, with the land area lying to the east. Progressively the land area was elevated and the ocean was driven back by the westward migration of the coastal line, a progress continuous throughout Coal Measure time, as has been fully explained in Volume III of this series of reports. Little by little the land area increased in size by the westward progression of the shore until, at the close of the Coal Measure period, the conditions above mentioned were devoloped.

Throughout the time just referred to sedimentation was a continuous process, forming the heavy Coal Measure shales and limestones which underlie the Permian, and which aggregate in Kansas about 3,500 feet in thickness. Step by step our state was built up by the slow but persistent accumulation of sediments, and the continuous westward migration of the ocean shore. Bed after bed was formed in this way, generally reaching eastward to the then coastal line and extending westward for unknown distances. Each succeeding bed, therefore, overlies the preceding ones, but its eastern limit is further west than that of those below it.

The same land movements which drove the ocean waters westward throughout Coal Measure time continued throughout the Permian and later times until finally the whole of the great expanse of ocean water, which may be called the "Mediterranean

Sea" of Permian time, was replaced by dry land. The elevation processes, however, were slow and irregular with many returns to former conditions, so that, as emphasized by Grimsley, the particular area in which gypsum was being deposited one time might be a site of limestone or shale accumulation at a later period.

The formation of gypsum requires the concentration of ocean water. This must have been brought about by the temporary separation, here and there, of bodies of ocean water from the main ocean so that evaporation could concentrate the liquid. There is little evidence to show that such bodies of concentrated water were particularly large. On the other hand it is highly probable that in each individual case such inland seas or lakes were relatively small, so that the formation of gypsum at any one particular time and place may not have covered many townships in extent. At this late day it is impossible to determine the exact limits of such gypsum beds. Erosion has worn much of the surface away and may have destroyed untold quantities of gypsum. Percolating ground waters likewise have dissolved portions, as Grimsley particularly shows for the Blue Rapids area, and therefore we are left to surmise the former maximum extent of such masses from the conditions as they now exist.

It is interesting to note the geologic succession of the various gypsum deposits in this great western interior region. In Texas they seem to be confined to the Permian. In Kansas they extend from the lowest Permian up into and nearly through the Red Beds, while in Iowa they are in the Cretaceous. In a general way, therefore, there is a migration upward corresponding to one northward. But in detail the Kansas deposits are just the reverse, passing from the lower Permian on the north to the upper Red Beds on the south. This may imply local and earlier elevation into dry land conditions in the northern part of the state, and a later one along the southern line. The general geologic conditions, however, show this much more conclusively. The Permian rocks at the north line of the state are thin and belong to the lower Permian, and are immediately overlaid by the Dakota Cretaceous. Southward the Permian thickens, driving the eastern limit of the Cretacous further to the west

until along the south line of the state the Permian and Red Beds combined have a thickness nearly ten times as great as the Permian has at the north Kansas line. Within Kansas territory, therefore, the Permian ocean was driven southwestward rather than westward, as is abundantly proved by the extraordinary thickening southward of these formations.

At the close of the Permian period, however, it seems that throughout the whole of the "Mediterranean Sea" the reverse conditions obtained, so that ultimately the great inland sea was driven northward into the Arctic ocean. This phase of the subject was discussed at considerable length in Volume II of this Survey, and was illustrated by Plate XXVI, which shows that within Kansas there is a great thickening of the Cretaceous beds to the north corresponding to the thickening of the Permian beds to the south; and the further fact, well established, that in the southern part of Kansas, and much more markedly so south through the Indian Territory and into Texas, the lower Cretaceous beds only are found, while in northern Kansas and Colorado and further to the north the upper Cretaceous occurs in great abundance.

This leveling up, so to speak, of the horizons by the thickening of the Cretaceous formations over the territory where the Permian was the thinnest is an interesting point in connection with the geology of the formations laid down in the great "Mediterranean Sea" area and confirms the view already stated, as emphasized by Grimsley, that throughout the period of gypsum formation there was a great lack of stability in oceanic boundaries which made it possible for the frequent embayment of bodies of ocean water, so that by their surface evaporation gypsum deposits could be produced, and that the same irregularity in stability of conditions produced such deposits at various times and in various places throughout the great western interior area. Sometimes two or more beds of gypsum are found one above the other, implying a repetition of such conditions in the same locality with an interval of sedimentation between, but generally the series of conditions have migrated southwestward as time advanced.

PREFACE.

BY G. P. GRIMSLEY.

ONE of the main objects of the University Geological Survey of Kansas is the investigation of the mineral wealth within our borders. It is important not only that our own citizens should be informed about these resources, but also that people in other states should know that Kansas is a mining as well as an agricultural state. It is a matter of surprise to find how little is known by Kansas people about the state's mining interests. The Survey has already done good work in calling attention to these various minerals, the value of whose aggregate product in 1897 amounted to nearly $12,000,000. Gypsum was the fourth non-metallic mineral in value of product, being surpassed by coal, salt, and clay. Its value that year was over $252,000.

The problem of mapping and investigating the gypsum or plaster deposits was assigned to the writer in the winter of 1896, by Professor Haworth, who has very materially assisted in the preparation of this Report.

Two summers have been spent in actual field work. The first summer Mr. J. W. Beede, now a graduate student in Paleontology in the University, assisted in part of the work in southern Kansas. In the summer of 1897 I had the services of Mr. Henry Nelson, one of my students in Geology, as assistant.

It has been deemed best to include a general discussion of the gypsum deposits of other states for comparison. An effort has been made to have the treatment of this subject as complete as possible and to bring together in compact shape all that is known about gypsum and its technology.

This industry is in reality in a beginning stage of development. It is rapidly growing, and to-day Kansas stands first among the states of the Union in value of the gypsum product.

Even with this high rank, it is important to remember that the deposits are merely opened and large quantities remain yet to be worked. In the southern Kansas field, where there are miles of gypsum, there is but a single mill in operation.

Nowhere in this country are better gypsum plasters made than in Kansas, and these cement plasters find a ready and increasing market in the east, even where other deposits have the great advantage in freight rates on account of the shorter mileage.

The writer is indebted to many persons for kind assistance in the preparation of this volume. The chemical work is included in the chapter by Prof. E. H. S. Bailey, of the Department of Chemistry in the University.

The officers of the various cement plaster companies have given cheerful assistance in the collection of data; and the various manufacturers of gypsum machinery have aided with descriptions and drawings.

The writer wishes to express his thanks and appreciation for these favors, and for the many others which cannot here be mentioned, and it is hoped that this report may serve to advance in some degree our plaster industry.

TOPEKA, KAN., November 15, 1898.

CHAPTER I.

HISTORY AND DISTRIBUTION OF GYPSUM DEPOSITS.

Gypsum with the Ancients.

THE sulphate of lime, or gypsum, has the chemical formula $CaSO_4 + 2H_2O$. When the water is absent the mineral is called *anhydrite*, a form rarely found in nature and which is of no economic importance. The derivation of the word gypsum is not known. The origin often given, from two Greek words, γῆ = earth and ἕψω = to concoct, is without much doubt erroneous.

The mineral has been used in various ways from very remote time. Pliny records that the conservatories were glazed with transparent gypsum, called *lapis specularis*, for preserving fruit-trees in winter, and that beehives were thus rendered transparent so the curious could see them working. On account of the soft lustre given to the light as it passed through these transparent plates, these ancient people were reminded of the light from the moon, and so named this variety of gypsum *selenite* from σελήνη = the moon. Selenite was regarded by these people as the most delicate variety of alabaster and was used by the wealthy in their palaces for windows, receiving the name of Phengites. It is said to have possessed the peculiar and very convenient property of enabling a person within the house to see out, while those without could not see in.

The walls of the old temple of Fortuna Seia were constructed of stone supposed to be compact gypsum and "the interior though without windows was rendered sufficiently light by rays transmitted through its semi-pellucid walls."[1] At Florence,

1. Rees' Cyclopedia of Arts, Sciences, and Literature, 1814.

the gypsum of Volterra was made into vases in which lamps were placed, throwing a soft light over the room. In Arabia the building of Arsoffa Emii, supposed to be an old monastery, is constructed of gypsum,

"and when the sun shines on it the walls give such a lustre that they dazzle the eyes, but the softness of the stone and redness of the mortar have conspired to make it a very ruinous pile at present, though of no great antiquity; the stone having split and mouldered away in the wall and the foundation has failed in many places."[2]

The writings of Theophrastus and Pliny show that the Greeks were familiar with the use of plaster, made by calcining the gypsum stone, in making casts. They state that the first plaster casts were made by Lysistratus of Sicyon, who was a brother of the famous sculptor, Lysippus. He made first a cast in plaster from the object and from this obtained a second one in wax. Rhaecas and Theodorus of Samos worked by the same method, but the art appears to have attracted very little attention and was soon neglected and in course of time forgotten. It was revived by Verocchio (1422–1488) and others when the method of casting in plaster proved of great service in obtaining copies of the specimens of ancient sculpture which were then discovered.

The compact variety of gypsum, or alabaster, is frequently referred to in the ancient writings; though this word was so often used to describe the stalactitic carbonate of lime, that it is not always possible to tell from the meagre descriptions whether the alabaster mentioned is the sulphate or carbonate of lime.

The derivation of the word is a much disputed question. According to some writers it is derived from the two Greek words, α = without, and λαβαί = handles, referring to a box without handles made from this material and used to hold perfume. This derivation is said to be inconsistent with the rules of formation of the Greek language, and the derivation was probably given long after the word itself was coined. A similar derivation, more consistent with Greek rules, gives an origin based on physical character, from α = not, and λαμβάνω

2. Rees' Cyclopedia of Arts, Sciences, and Literature, 1814.

(Latin *Capio*) = to take, so named because the rock is smooth and slippery and difficult to handle. Another writer gives an Arabic origin, from *al batstratron*, meaning a white stone. Some even connect the word with the Latin *albus* = white. A derivation which seems most probable connects the word with the town of Alabastron, in Egypt, where in early times there was a manufactory of urns, vases and other ornaments made from the gypsum stone found in the mountains near by. This old town was situated, according to Mr. James Burton, south of the ruins of Antinoe, on the east bank of the Nile, in latitude 27° 43′ and longitude 30°. The word alabaster was also used by the ancient people for a liquid measure which would hold ten ounces of wine or nine ounces of oil.

The alabaster used in these early days came mainly from Syria and upper Egypt. The statues and basso relievos of the mausoleum of the Connetable de Lesdiguieres, of the Cathedral of Gap, were made from alabaster taken from Boscadon near Embrun, in the High Alps. Important deposits were found near Coblentz in Germany, near Cluny in France, and near Rome in Italy. The Encyclopedia Perthensis, written in 1816, states that

"There is a church in Florence still illuminated, instead of by panes of glass, by slabs of alabaster near fifteen feet high each of which forms a single window through which light is conveyed."

Eighteenth Century Gypsum Literature.

Gypsum rock was not very thoroughly examined or investigated until the present century. Chambers' Dictionary of Arts and Sciences in 1753 gives the following summary of the knowledge concerning this mineral down to that time:

"Gypsum in natural history, the name of a class of fossils; the characters of which are these: They are composed of small flat particles irregularly arranged, and giving the whole masses something of the appearance of the softer marbles; they are bright, glassy, and in a small degree transparent; not flexile nor elastic, not giving fire with steel, nor fermenting with or dissoluble in acid menstruum, and calcine very readily in the fire. Of this class of bodies there are two orders, and under those, four genera. The first order is of the *gypsums* which are of a firm, compact texture and considerably hard. The second, of those which are of a lax or loose texture and are accordingly soft and crumbly.

"The genera of the first order of the *gypsums* are these: 1. Those which are

hard, composed of somewhat broad particles, and of a bright crystalline lustre, the *pholides;* 2. Those of a softer texture composed of very small particles and of less glittering hue.

"The genera of the second order are: 1. Those of a softer texture which are very bright and glittering, the *timachides;* 2. Those of a softer texture which are dull and opague, the *clasmia.* All the species of this whole class burn with a very slight degree of fire to what is commonly called plaster (plaister) of Paris, but the softer requires the smaller degrees of fire, and in general the hard and more marbly make the better plaster.

"The common way of burning the stone into plaster is too slight to give it all the hardness it is capable of. It is reported by many that a great degree of heat renders it greatly superior in hardness, and it is said that the artificial marble, with which the whole palace of Munich is adorned and which the elector of Bavaria esteems more than marble, for which it is mistaken by all that see it, is made of the common *gypsum*, fire burnt in the ordinary way, and afterwards put over the fire again in a copper vessel and suffered to boil, as it will like water for a long time. When this boiling ceases of itself, the matter is taken out, and common colors, such as are used in painting, are mixed with it in various proportions; which, on the wetting it with water and working it in the common manner of plaster of Paris, diffuse themselves and imitate the veins of natural marble.

"Gypsum is used in Canaries by way of remedy for their wine and about Malaga a large quantity is tunned up with the juice of their grapes."

The first edition of Chambers' Dictionary, published in 1741, describes alabaster or compact gypsum in the following words:

"Alabaster, a kind of stone softer than marble yet harder than plaster of Paris, is used for the making of figures and other ornaments of sculpture. Alabaster, Mr. Boyle observes, being finely powdered and thus set in a basin (bason) over the fire will when hot assume the appearance of a fluid by rolling in waves yielding to the smallest touch and emitting vapor, all which properties it loses again on the departure of the heat and discovers itself a mere incoherent powder."

Varieties and Distribution of Gypsum.

Gypsum occurs in nature in five varieties: 1. Earthy, of yellow or gray color, composed of loose particles, light in weight, and formed by precipitation from solution of gypsum in water; 2. Compact or massive, including alabaster and gypsum rock, very soft, with specific gravity of 2.28 to 2.31, and with typical composition 32½ per cent. of lime, 46½ per cent. of sulphuric acid, and 21 per cent. of water; 3. Fibrous gypsum or satin spar, usually found in thin layers in form of fine needles or prisms; 4. Foliated gypsum, in round or concretionary masses; 5. Spar gypsum or selenite, found in transparent plates and crystals.

Gypsum is found in Thuringia, Saxony, Norway, at Mont Marte near Paris, Austria, Bohemia, Italy, Egypt, Arabia, Persia, and many other places in the old world. In this country it occurs in small quantities in most of the states of the Union, and it is of economic importance in many of these. Wherever this mineral is found, it has attracted attention, and we now have good descriptions of the extent, origin, and uses of gypsum in the leading producing states of the union.

Gypsum in New York.[3]

The gypsum deposits of New York state occur in the Salina or Onondaga formation of the Upper Silurian period, and occur in regular beds, which plainly show it was originally deposited from water. Mr. Clarke states in his report that no evidence of gypsum is found east of Madison county, and that towards this eastern limit the gypsum is of a much darker and more earthy type, probably due to presence of carbonaceous matter. The dark variety lies near the surface, while whiter gypsum at west is generally heavily capped with rock, and has less thickness than the other.

The largest quarries belong to the Cayuga Plaster Company, of Union Springs. The beds have been worked for fifty years and about fifty tons of rock are quarried per day. The gypsum is covered with earth and underlaid with limestone. The beds are exceptionally regular and persistent and surface inequalities do not appear to influence the gypsum except in thickness. The plaster is shipped to other parts of the state and adjoining states and used as fertilizer. The color of the rock is gray with plates of selenite more or less intermingled, and large crystals are sometimes found. Weathering action disintegrates the gypsum, breaking it into dirt and small pieces which are not used at the mill. The rock has a maximum thickness of 40 feet while the average is about 8 feet of top rock and 8 feet of bottom rock. Other mills are located to the west. At Garbuttsville, in Monroe county, the Caledonia White Land Plaster is made

3. Condensed from New York Reports: Bull. State Museum, Vol. 3, No. 11, by Wm. C. Clarke, pp. 70-84, 1893. Same, Vol. 3, No. 15, by F. J. H. Merrill, Ph. D., p. 550, 1895.

from a plaster rock with average thickness of 6 or 7 feet. The gypsum is covered by a water lime and rests upon a limestone. The various pits to the west work a plaster rock of about 6 feet in thickness. The section of gypsum rock shows 18 feet of hard bottom, 18 feet of white gypsum, and then 6 or 7 feet of gray rock. At Oakfield, in Genesee county, where there are three plaster quarries, the deposit of plaster rock is only 4 feet thick and is of very white color. Prospecting for gypsum throughout the state centers on the knolls or rises in ground. Near Alabama station, in Genesee county, is the farthest west the gypsum is worked in the state. In the region near Fayetteville the combined product makes it the second largest producer of plaster.

Drilling shows that under Buffalo[4] at a depth of 50 feet there is a deposit of over 20 feet of white gypsum. Attempts were made by the Buffalo Cement Company to mine this by sinking a shaft, but the inflow of water stopped the work and it was abandoned.

The greatest thickness of gypsum rock in the state is near Syracuse, at the Severance quarry, where the rock is 60 feet thick in places, and divided into eight well-marked layers varying in thickness from 18 inches to 30 feet. The deposit is covered with 30 to 40 feet of shaly rock and limestone. The amount of lime sulphate is greatest in the crystalline layers and least in the brown layers. The rock varies in color from light drab in the cap to a dark brown, and all layers appear to become lighter from weathering. The so-called slate consists of fibrous, scaly and other forms of crystalline gypsum, and is essentially the purest gypsum of the series. The rock is reported as suitable for plaster of Paris or stucco for walls.

Twenty-two companies are engaged in quarrying the gypsum which is found in Madison, Onondaga, Cayuga, Ontario, Monroe and Genesee counties. The approximate yearly tonnage is given as 37,000 tons, with an average price of $2.75 per ton, or a total value of $100,000. According to the reports of the

4. Cement Rock and Gypsum Deposits in Buffalo, by Julius Pohlman, Transactions American Institute of Mining Engineers, XVII, p. 250, 1888-'89.

United States Geological Survey for 1895, New York produced 33,587 tons of gypsum, of which 12,182 tons were sold crude, 16,765 tons were ground into land plaster, and 4640 tons were calcined into plaster of Paris; with a total value of $59,321.

Mr. Clarke, in a summary of the gypsum industry of New York, states:

"The gypsum business is not as a general thing conducted on an all-the-year-round basis. The quarrying is to a large extent done by farmers who work their farms in the season and employ their hands in the quarries when there is little farm work to do. This may account to some extent for a variation in the tonnage each year. No trouble with water is experienced. The employment of skilled miners with modern and improved implements would effect great economy in the cost of producing the gypsum. Even the use of a light track of hoop-iron and small cars would be of advantage in transportation. The introduction of steam drills, the drilling of larger holes and the use of larger blasts would increase the output greatly with the same force of men. It is well known that a considererable amount of the plaster goes into the composition of the high-grade fertilizers. With the increase of the adamant wall-plaster business there will probably be an increase over present production of the gypsum business of New York state, but as this business is hardly well started yet, the effect may not be noted for some time."

Nearly all the gypsum product of New York is ground and used as land plaster for fertilizer.

Gypsum in Ohio.[5]

Orton states in his report that land plaster or gypsum is quarried at the single locality near Gypsum station, Ottawa county, in the northern part of the state, ten miles west of Sandusky:

"The mineral has been known here since the first occupation of the country, coming to view in the rocky floor of Sandusky Bay, immediately adjacent to which the quarries are located. Not more than twenty-five acres have been already worked out, and there is probably as much more territory that has been proved to contain gypsum in quantity to justify working, while a larger acreage to which no thorough tests have yet been applied may be reasonably expected to hold valuable deposits. Most of the proved territory is included in the two hundred acres that Marsh & Company own, but in past years quite a large amount has been taken from the farm adjoining this upon the west. The surface, which is composed of the usual drift clays, is but a few feet higher than the waters of the bay. In the quarries that have been thus far worked, the drift has been very shallow, being confined mainly to troughs or hollows in the limestone, the results of earlier erosion."

5. Geological Survey of Ohio, Vol. VI, Orton, pp. 696-702, 1888.

The geological age of the deposits is Lower Helderberg, a formation with maximum thickness of 700 feet, and gypsum occurs through it at various places, and the mineral is found in most of the deep wells drilled in northern and central Ohio. The gypsum beds, according to Orton, are not even and horizontal, but are found in waves or rolls, whose summits rise 5 to 8 feet above the general level. The main plaster beds are about 12 feet thick, and would yield 50,000 tons to the acre. No fossils are found, and Orton regards the origin of the gypsum as due to a deposit from a shallow, land-locked and contracting sea during the Lower Helderberg period. The first deposit would be the sulphate of lime in form of gypsum or anhydrite. The shallowness of sea is established by the sun-cracks and wave marks that are well shown in these rocks.

The gypsum is used as land plaster and calcined into plaster, in proportion of about 60 per cent. of the first and 40 per cent. of the second, but the total value of the calcined plaster is greater than that of the land plaster. In 1895[6] Ohio produced 21,662 tons of gypsum; 6914 tons were sold crude, 3048 tons were ground into land plaster, 11,700 tons were calcined into plaster of Paris, with a total value of $71,204.

Gypsum in Pennsylvania.[7]

In Pennsylvania gypsum occurs in the Lower Helderberg in thin seams intermingled with mud veins, and the whole series lies just below a drab, impure limestone. The origin is regarded as due to an alteration of the limestone to gypsum through the agency of sulphur spring water. The deposits are not of economic importance.

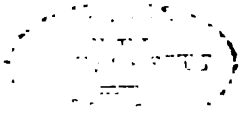
Gypsum in Michigan.[8]

The gypsum deposits of economic importance in Michigan are found in two localities. The most extensive are near Grand Rapids, in Kent county, in the western part of the state. The gypsum covers an area of about ten square miles, and lies from

6. U. S. Geol. Surv., 17th Annual, Pt. III, p. 979.
7. Geol. Surv. of Penn., Summary Final Report, Vol. 2, pp. 913 to 915.
8. Mineral Statistics of Michigan, pp. 3-20, 1881.

VIEW IN MEDICINE LODGE RIVER VALLEY, NINE MILES S. W. OF MEDICINE LODGE.

Photographed by Grimsley, 1897.



2 to 70 feet below the surface. The upper bed is 6 to 8 feet thick, and is separated by a 1-foot seam of soft shale from the lower 12-foot ledge. Five companies are engaged in the plaster manufacture at this point.

In the eastern part of the state, near Alabaster Point in Iosco county, a large deposit of gypsum is worked. At the quarry of the Western Plaster Works the rock is 20 feet thick, and of fine quality. The Michigan deposits are Lower Carboniferous in age, and a very large portion of the gypsum rock is ground for land plaster or fertilizer. The production commenced about 1856, and the manufacture of plaster of Paris began in the sixties.

Gypsum in Virginia.[9]

The gypsum deposits of Virginia are found in the southwestern portion, in Smyth and Washington counties especially.

Near Saltville the rock is nearly 600 feet thick. It is stated that the amount must be estimated in square miles rather than acres. Up to present time the output has been small, amounting to some 6000 tons.

These eastern and central deposits belong to the earlier part of the Paleozoic era of geological time. In the west central region of the Mississippi valley occur valuable gypsum deposits which are more recent and belong to the closing part of the Paleozoic and Mesozoic time. The rock is found in Iowa, Kansas, Arkansas, Oklahoma, Indian Territory, and Texas.

Gypsum in Iowa.[10]

The gypsum deposits of commercial value in Iowa are found in Webster county in the north central portion of the state, in the vicinity of Fort Dodge. They were first described by Owen in 1852, and the mineral was described later by Worthen and others. The area covered is nearly fifty square miles, in the shape of an irregular triangle or rectangle, and the gypsum trends northeast and southwest nearly at right angles to the valley of the Des Moines river. Topographically the area is

9. Resources of Southwest Virginia, Boyd, pp. 104–108, 1881.
10. Iowa Geological Survey, Vol. III, Keyes, pp. 260–304, 1895.

a nearly level prairie, with imperfect drainage, and deeply trenched by the Des Moines river. The gypsum beds are regarded as Cretaceous in age, and rest upon the Lower Coal Measures, and are covered by the glacial drift. At the base of the gypsum is a layer of red sandy or clayey nodular shale of variable thickness. The character of the gypsum, as given by Keyes, is as follows:

"The gypsum deposits vary in thickness from 3 or 4 to 30 or more feet, the average measurement being about 16 feet. The gypsum is the perfectly massive variety, made up of numerous thin, alternating bands of white and gray calcic sulphate, the differently colored layers measuring from one-eighth to one-half of an inch in thickness, and finely corrugated. The lower part of the deposit, although not strikingly different from the upper portion, often contains some impurities, and on this account this part is usually ground into land plaster, while the upper portion is made into stucco. The gypsum beds appear to be thoroughly crystalline throughout, the individual crystals being columnar or needle-like, arranged closely together with their long axes at right angles to the sedimentation planes. This arrangement seems to be uniform throughout the entire deposit."

Well borings seem to show a considerable extension of the gypsum beyond the limits of known outcrop, both northeast and southwest of the Fort Dodge district. The deposit was probably laid down in a shallow estuary which extended out into a broad open sea in Niobrara epoch of Cretaceous time. The Iowa gypsum is used mainly for stucco or plaster of Paris and a small amount as land plaster. Some years ago the rock was used for building purposes and for flagging for walks, and the blocks stand without crumbling except on the surface, which becomes bleached and finely cracked. Keyes has computed that the available supply of gypsum in this region is more than 40,000,000,000 tons, and at present rate of production would last 800,000 years. The gypsum is easily quarried and transportation facilities are good. The product is shipped north, west, and south, and the land plaster is sold mainly in Wisconsin.

Gypsum in Indian Territory and Texas.

To the southwest, in Indian Territory and Texas, large deposits of gypsum occur. Marcy's Red River Report[11] in 1852 states that near the source of that river the waters have a pe-

11. Pages 52, 91, 172, 173.

culiar taste, received in flowing for one hundred miles over a gypsum formation, which he described as follows:

"I have traced this gypsum belt from the Canadian river in a southwest direction to near the Rio Grande in New Mexico. It is about fifty miles wide upon the Canadian, and is embraced within 99° and 100° meridians of west longitude. Wherever I have met with this gypsum I have observed all the varieties from common plaster of Paris to pure selenite. I regard this gypsum belt as a very prominent and striking feature in the geology of the country. From its uniformity and extent, I do not think there is a more perfect and beautiful formation of the kind known. I have myself traced it about three hundred and fifty miles, and it probably extends much farther. . . . The only deposits known to me as more extensive are those in South America, described by Darwin in his geology of South America. Very probably the ancient igneous agency in the Wichita mountains, and along a line southerly to the Rio Grande may have been concerned with the production of the gypseous deposit of the same region."

In Texas, Dumble[12] reports valuable gypsum beds in the lower Comanche series of Burnet county, Texas. In the Permian, the beds are numerous and often of considerable thickness. The clay is traversed in every direction by seams of fibrous gypsum, varying in thickness from paper-like seams to 10 feet, while the compact gypsum reaches 25 feet.

"In places a large deposit of gypsum appears, which on the surface consists of a loose material ready to be shipped as fertilizer without grinding. Below this, crystalline gypsum appears in thickness of several hundred feet. This and the selenite deposit will make excellent plaster of Paris, and the finer granular varieties are fit for works of art."

The valuable deposits of northern and western Texas, Dumble believes were deposited in an arm of the sea cut off from the old Permian ocean. The rock is used for plaster of Paris, wall plaster, and fertilizer. The fertility of the river valleys is regarded as due in part to the fact the rivers have their sources in the gypsum beds.

Gypsum in California[13] and Rocky Mountain States.

At Coalinga, Cal., a 10-foot stratum of gypsum has been mined since 1892, and sold as fertilizer in Tulare and Fresno counties. In the latter county, near Mendota, is the Paoli mine, discovered in 1892. The gypsum on the crest of the ridge at Paoli mine is at least 30 feet thick, and there is some indication

12. First Annual Report, pp. 123, 188, 193. Second Annual Report, pp. 455, 456, 700.

13. California State Mining Bureau Bull. 3, p. 63, 1894. 12th Report State Mineralogist of California, pp. 323-325, 1894.

that the upper layer may be connected with an 18-foot stratum, 150 feet below in a deep canyon. The average purity is thought to be above 90 per cent., and it has been extensively used as land plaster through the San Joaquin valley. Other smaller deposits are found in this valley, and Hilgard pointed out some years ago that portions of the rock could be burned into plaster of Paris.

In the northern part of Los Angeles county, in the Antelope valley, an area of twenty-five acres is covered with a surface gypsum stratum 25 feet thick. The rock is shipped to Los Angeles, where it is ground mainly for land plaster, though a small amount is made into plaster of Paris and wall plaster.

In Riverside and Santa Barbara counties gypsum of good quality is mined, but the outcrops are apt to be more or less broken and occur in Tertiary clays.

Gypsum also occurs and is worked in Wyoming and Colorado.

Gypsum in Canada.[14]

Gypsum is found in the Lower Silurian or Ordovician rocks in Quebec, in Upper Silurian in Ontario, and in Lower Carboniferous in the maritime provinces. It occurs in very heavy beds through the Lower Carboniferous strata of northern Nova Scotia. The deposit is almost inexhaustible, and is shipped from Windsor, Cheverie, Walton, and other places, mainly to the United States. Gypsum occurs in large amounts at other places in Nova Scotia, as near Antigonisti, where a cliff of white and red gypsum 200 feet in hight overlooks the ocean.

It is found in large amount in New Brunswick. It is quarried at the Albert mines, where the rock is 60 feet thick, and it is calcined in large works at Hillsborough. In the valley of the Grand river, from Cayuga to Paris, a distance of forty miles, gypsum of Upper Silurian age outcrops in lenticular beds. Gypsum of Devonian age is seen in strata of 10 to 20 feet thickness for seven miles along the Moose river.

Gypsum occurs in northern Manitoba in two beds, 22 and 10 feet thick, and northwest along the Mackenzie river; also on Salmon river, in British Columbia.

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14. The Mineral Wealth of Canada, Willmott, pp. 105–111, 1897.

CHAPTER II.

GEOGRAPHY AND TOPOGRAPHY OF THE KANSAS GYPSUM AREA.

Geographic Location and Division of Deposits.

The Kansas gypsum deposits of economic value form a belt trending northeast and southwest across the state, as shown on the map in Plate I. The belt of exposed rock varies in width from five miles at the north to twenty-five miles in the central part, and to 140 miles near the southern line, with a length of 230 miles.

This area is naturally divided into three districts, which, from the important centers of manufacture, are named: The northern or Blue Rapids area, in Marshall county; the central or Gypsum City area, in Dickinson and Saline counties; and the southern or Medicine Lodge area, in Barber and Comanche counties. These areas appear to be separate, but careful mapping shows a number of isolated intermediate deposits, which serve to connect the northern and central areas, and indicate connection between the central and southern areas. These connecting links are found near Randolph and in the reservoir excavation at Manhattan, in Riley county; at Longford, in the southern part of Clay county; and near Manchester, in the northern part of Dickinson county.

Gypsum deposits of economic importance are found near Peabody and Burns, in Marion county; in Sedgwick county, near Mulvane, and in Sumner county, near Geuda Springs.

From an examination of a map of west central United States with the gypsum deposits indicated thereon, it will be seen that if the northeast line of the Kansas deposits is extended it will

strike the Fort Dodge area in Iowa, and if it is continued to the southwest it will strike the extensive deposits of the Canadian river in Indian Territory and those of Texas.

Topography and Its Evolution.

In order to understand and be able to interpret the topography of the Kansas gypsum belt and its problems, we will go back in imagination to the time when an area of sediments like the early Kansas land first emerged from under the sea, before the forces of earth and air commenced to fashion and mould it into the varied patterns of nature.

Such a review will enable us to understand more clearly the conditions we find to-day in this belt; and it will also teach the useful lesson that the land has not always possessed the appearance it has to-day, but that the familiar objects of river and valley, hill and dale, are transitory features on the earth's surface. Everything changes and grows old, even the so-called everlasting hills; and all conform to the universal law of nature—adjustment to environment or to surrounding conditions. This law only in late years has been discovered reigning in the inorganic world of rock and cliff, and it is no longer connected solely with organisms.

This is a comparatively new phase in geology, and so is often set apart as on a pedestal under the term of New Geology. But it is new because of progress in the science, and merely represents new methods of study in old structures. It has added life and interest to our study of inanimate nature, and it is but proper that it should form a part of our present chapter on topography.

STREAM GROWTH.

If a sea floor is elevated several hundred feet into dry land, as has happened many and many times in the history of the earth, the surface will be approximately smooth. As the rains fall upon the broad level plateau the surface will be roughened and the water will collect in small rills and rivulets, just as we see to-day on any exposed surface after a rain. These rivulets will flow together, forming larger ones, and pursue their paths

seaward. Some of these little streams will gain an advantage over others, because of more favorable conditions, such as softer rock, greater slope, and the like. They will thus form deeper channels, and will take the water from the less favorably located channels. By increase in slope and in volume of water greater and greater erosion will result, and the channel will become deeper and deeper, causing the rivulet to grow into the creek flowing in its ravine, and this in turn will grow into the river flowing in a valley which it has worn. The smaller and less favorably located rivulets become tributaries to the larger ones, and they increase in size as the main stream grows, so that there finally results a well developed river system, with main streams and tributaries branching in all directions, like a great tree.

The smooth upland or plateau becomes furrowed with valleys, at first separated by broad divides. Where obstructions are met, there the water is held back, forming lakes which later will be filled up with sediment or destroyed by the stream breaking through the barrier. If the river crosses a hard stratum of rock in its course, it will cut slowly through it, and more rapidly in the softer strata below, and so a projecting shelf of rock will be left over which the water will fall in a cascade. This hard stratum finally will be eroded away and the waterfall disappear.

This early period in the stream's history, from analogy to the growth of an organism, has been termed the period of *infancy*. During this time the amount of erosion work accomplished by the stream is not as great as later in its history because the slopes are not as great, volume of water is smaller, and the tributaries fewer in number. At this time there is more or less change in course through the selection of more favorable paths.

As the river cuts its channel deeper, the heads of the streams work backward in their different directions, narrowing and cutting across the divides. The valleys are further widened by the action of rain, frost, wind, and all the forces of the atmosphere, until the plateau becomes dissected and extremely irregular. The river now does its maximum work of erosion and carries a

large amount of sediment from the hills and valley slopes to the lower levels, where it is deposited. The river is now said to be in a stage of *maturity*.

The divides are cut down more and more until the old plateau comes nearer and nearer to a smooth plain of much lower level, the plane of erosion or base level. The velocity of the stream becomes less and less; the river does very little work of erosion, and it has now entered the period of *old age*. When the river bed finally is at the level of the sea the current is stopped and the river is *dead*.

Such a history comprises the theoretical cycle of a river and through it every river will pass in the course of time. A very long time may be taken for this cycle and as yet probably no river has ever passed through it, for our land is nowhere very old since its last elevation. Our rivers over the land are in various parts of the cycle.

When the history of rivers is carefully studied it is found to be much more complex than the outline given, for movements of elevation of the land may throw the period in the cycle of a river back again to an earlier one; or movements of depression may change the period to a later portion of the cycle. The variations which complicate the history need not be mentioned in this place, but enough has been given to show that the topography or relief of the land is dependent for the most part on river development and the accompanying forces of the atmosphere.

With the general history of river development in mind, we will see how far it applies to the development of the topography of the region now under discussion.

TOPOGRAPHY OF NORTHERN OR BLUE RAPIDS AREA.

The phrase "low, monotonous prairies of Kansas" has no application to the gypsum belt, for there this feature is entirely absent. The northern area, Plate II, is a dissected plateau, of about 1300 feet elevation,[15] which is now so indented by the Big Blue and Little Blue rivers, with their smaller tributaries, as to

15. Elevations in this paper are taken from the United States Geological Survey topographical maps of Kansas.

IN THE GYPSUM HILLS, SOUTH OF SUN CITY, BARBER COUNTY.

Photographed by Grimsley, 1897.

VIEW ACROSS GYPSUM HILLS, FROM BEST'S GYPSUM QUARRY, BARBER COUNTY.

Photographed by Grimsley, 1897.

present a rugged topography. The agents that did this work were the Big Blue river, which has its source in southern Nebraska and flows nearly south through a valley of one-half to to one mile in breadth and 100 feet deep, and the Little Blue, which rises at the west, in Republic county, and flows through southern Nebraska and southeast through northern Kansas in a valley of varying breadth and about the same depth as that of the other river. The rivers unite near the town of Blue Rapids and furnish, at that place, the best water power in the state, estimated at 1500 horse-power at low water. The Big Blue then flows south thirty-five miles, emptying into the Kansas river near Manhattan.

The valleys and hills of this northern area are covered with fertile lime soils, and they are dotted with prosperous farms. The small towns are located close together in the valley of the Blue and are connected by the northern branch of the Union Pacific railroad. The plaster manufacture is the prominent industry of Blue Rapids, a town of about 1200 inhabitants, where there are three gypsum mills and a fourth one in prospect.

TOPOGRAPHY OF CENTRAL OR GYPSUM CITY AREA.

The central area, as shown in Plate III, lies seventy miles southwest of Blue Rapids, and the area of important gypsum deposits lies south of the Smoky Hill river, north of the Rock Island railway, and west of the Atchison, Topeka & Santa Fe railway. The area is drained by the Smoky Hill river, which flows in a very winding channel north of east, uniting with the Republican river thirty miles away at Junction City to form the Kansas. It flows in the middle of a broad valley 1100 feet above sea level and a mile or more in width. Its tributaries in the gypsum area are three small creeks, Gypsum, Holland, and Turkey, which flow almost directly north.

The main water-shed or divide formed by the Dakota sandstone lies twenty-two miles to the south of the river, and trends nearly east and west, with an elevation of about 1550 feet, through the northern part of Marion county. This divide descends on the south side within eight miles to 1400 feet in the

Cottonwood river valley. The north and south divides between the creeks have a gradual northward slope of about twenty feet to the mile, and their sides along the creeks are deeply indented by erosion. They vary in hight above the water level in the streams from 100 to 150 feet.

The area is a dissected plateau forming a very irregular surface near the divide, where it is more more or less protected by the Dakota sandstone. Toward the north where the Dakota is absent the topography is much smoother, and the surface slopes gradually to the Smoky Hill river.

The land in the northern part of this central area has about the same elevation as the northern gypsum area and the topography is quite similar. It shows a more advanced stage of erosion, for the remnants of the plateau in the form of divides are narrow, and the river and creek valleys are broader. The Smoky Hill river in its wide chanel has a very winding course, and is depositing material rather than eroding. It has cut its way down almost to the level of the larger river of which it is in reality a tributary. It has then nearly reached a base level with reference to the larger river, but it is still far above the true base level which is sea level.

In the southern part of the area, however, the land is higher and is protected by the harder rock, so that the topography is much rougher than in the other portion of the same area, or in the northern area. The streams have a greater fall and so a greater velocity, and erode more rapidly, while the hard sandstone protects the divides and they are cut into hills with steep slopes. Erosion as yet has not advanced as far in this portion of the central area as other parts. We can readily imagine that the cap of Dakota sandstone extended over at least a part of the northern portion of this area and now has been removed by erosion, though this does not at the present time admit of proof, as all traces of the sandstone there are lost.

A number of small towns are situated along the Missouri Pacific and Atchison, Topeka & Santa Fe railroads in the central part of the area, while larger cities lie along the river. The plaster manufacture is the main industry of this part of the

state, and this is the most important center for the production of plaster in Kansas. Five companies, with six mills of modern construction, are engaged in this work, which centers in the towns of Hope, Dillon, Solomon City, and, formerly, Gypsum City.

TOPOGRAPHY OF SOUTHERN OR MEDICINE LODGE AREA.

The southern area is situated 120 miles southwest of Gypsum City. Plate IV. The northern part is drained by the Medicine Lodge river, which rises in Kiowa county and flows southeast to Medicine Lodge, where it turns abruptly south, flowing into Oklahoma, and there it empties into the Salt Fork of the Arkansas river. The southern part drains into the Nescatunga river, flowing southeast through Comanche and Barber counties into Oklahoma, where it also joins the Salt Fork. The main branch north of the Medicine Lodge river is Elm creek, which has a channel parallel to the river, flowing south of east, and turning south following the course of the river. The creeks south of the river, Bear, Dog, Little Bear, Bitter, Cedar, Walnut, flow northeast in parallel channels. This uniformity in direction is a striking feature.

The divide between the two larger rivers is broad in Comanche county, with an elevation of 2200 feet just east of Coldwater, but it rapidly narrows to the southeast, in Barber county, where its elevation is 1900 feet, descending to 1600 feet in the valley of the Medicine Lodge river, within a distance of seven miles. Plate V gives a view of the river valley and Gypsum Hills in the distance. This divide trends parallel with the river and turns south near the central part of Barber county, still parallel with the river.

This area, as was stated under the geological section, consists of soft red shales covered by a heavy gypsum layer, as shown in Plates VI to X. The gypsum rock is soft, but much firmer than the friable shales below. The old plateau surface is at a much higher level than even the highest portion of the central area. All the conditions, therefore, have been favorable for rapid erosion, and the streams have cut deep valleys, separated

by narrow divides, which are now carved into towers and buttes of red clays and shales, which are supported by interlacing selenite layers, as represented in Plates VIII and IX. As the sun shines upon them a most beautiful effect is produced, which is sure to attract the attention of the observer, and gives a picturesque landscape of which he never wearies. The geologists and travelers who have discussed this region have given very poetical descriptions, and the area certainly is inspiring to those poetically inclined.

The buttes often rise 200 feet above the canyons and are capped by the massive white gypsum, producing an effect very much like that of the "bad lands" of the northwest. This appearance is well shown in Plates V and X. Atmospheric forces, especially rain and frost, have widened the upper portions of the stream valleys, giving the characteristic V-shaped form. The hills are more or less circular in outline, and their lower portions are hidden under a mass of fan-shaped talus. Plate XI.

The erosion at first is checked by the gypsum cap, but when that is cut through it goes forward very rapidly. In the early history of the area, the water doubtless poured over the white rock in a waterfall, which must have been of considerable size and beauty. Other smaller falls probably were formed when the streams cut down to the standstone layers below; but these features have now disappeared in the rivers, though they may still be observed at places in the smaller tributaries.

The amount of erosion is much greater than in either of the other regions on account of the more rapid development of the streams under the more favorable conditions of elevation and soft rock, but it is interesting to note that the streams have cut to nearly the same level here as in the central and northern gypsum areas.

These various streams, with their steep slopes, are dry through much of the year, the water running off rapidly into the rivers or disappearing in the soft, sandy beds. Some of these streams are very appropriately named Sand creek, Dry creek, etc. After heavy rains they become raging torrents of tumultuous sand and silt laden waters, which are almost impossible to ford, and

are active agents of erosion. The attempts which have been made to dam back the waters for a summer supply for stock have not been very successful, as the rush of waters soon carries out the obstructions. The traveler who is caught in the hills by a severe thunder-storm in summer is compelled to wait for many hours before he can safely find his way across the ravines.

This whole region presents the most rugged topography of the state, and forms scenery quite out of accord with the smooth topography which characterizes the state as a whole. Few people know or imagine that any portion of Kansas has such a rough surface as is shown in this area. It is especially interesting to the geologist through the lessons in erosion it so clearly depicts. We thus see that the erosion features and the resulting topography increase in complexity from north to south through this gypsum belt. The plateaus are more and more dissected southward, and give evidence of the great power of running water in modifying the surface appearance of our land. But it must be remembered that this is the relief of our time, and only a stage in the world's history.

CHAPTER III.

HISTORICAL RESUME AND GEOLOGY OF KANSAS GYPSUM.

The Kansas deposits early attracted the attention of geologists and prospectors. The Kansas Annual Register for 1864[16] states that west of Fort Riley there are large deposits of gypsum, or plaster of Paris, and very extensive chalk bluffs, both of excellent quality; also, that large deposits of gypsum occur along the banks of the Big Blue river, in Marshall county.

Report of Swallow.

Swallow, in the Preliminary Report of Geological Survey, issued in January, 1866, describes gypsum beds of the Triassic system, and says[17]:

"We have proved the existence of vast beds of gypsum cropping out across the central portions of the state and extending westward beneath the Cretaceous and Tertiary rocks. A large part of these beds are the pure white, granular sulphate of lime, most valuable in the arts. It is very much used in forming fine plaster and stucco work, for plaster casts, and for cements now extensively used in manufactures. But its well-known effects upon poor and even barren sandy soils give to this deposit a transcendent importance in central and western Kansas.

"These plaster beds will enable the farmer at small cost to render the poor, sandy ridges and plains in western Kansas as fertile as the rivers and valleys which have the wash from these beds. The quantity of gypsum in these beds is so great that they will easily supply the demand of the Mississippi valley for many generations."

Reports of Mudge.

In the First Annual Report on Geology of Kansas, in 1866, Mudge[18] describes the deposits of gypsum on the Blue river, 4 to 10 feet in thickness, and the central beds on the Saline,

16. Pages 76, 196.
17. Page 41.
18. Page 26.

Solomon, and Smoky rivers. He also discusses the uses of this mineral, especially as a fertilizer, and writes:

"While it is excellent for crops in various ways, its great worth to the Kansas soil consists in its hygrometric quality or virtue as an absorbent and fixer of certain volatile matters which are useful in plants, and particularly in retaining moisture in a condition that renders it available to the roots of plants and thus counteracting the drying and evaporating effect of wind and sun. This is an important quality which our farmers will readily appreciate, especially in portions of the state liable to drought. It retains the moisture to such a degree that a crop, particularly of roots, manured with it will sometimes be saved when an adjoining field will be dried up. Even a single bushel of the powder on a quarter acre of land will show a decided improvement in the crop. Its effect can usually be seen for several years after it is used."

Mudge's reports on gypsum, in the Third and Fourth Annual Agricultural Reports and in the First Biennial Report, 1877–'78, are mainly restatements of the description given in the First Annual.

Reports of St. John.

In the Fourth Biennial Report of the Board of Agriculture, 1885,[19] the gypsum deposits are described by St. John as follows:

"Intimately associated with the Saline horizon, in the uppermost measures of the Carboniferous series, immense deposits of gypsum are met with. These occur over a belt many miles in width, and which extends entirely across the eastern-central portion of the state.

"The deposits, which consist of gray and snowy-white varieties of great purity, form regular and lenticular layers interbedded with the shales and calcareous strata of the formation, often several feet in thickness. In the northern portion of the district, in the Kansas basin, beds of massive gypsum above 15 feet in thickness occur, and at many localities, at intervals, extending across the country to the Arkansas valley, on the southern border of the state, regular massive beds of various thicknesses are found. In the northern district, at Blue Rapids, extensive mills have been erected for the grinding of plaster for agriculture, and the preparation of plaster of Paris employed in the arts. At many places, also, the deposits are sufficiently compact and durable to answer the purposes of a building stone, for which it is employed."

In the Fifth Biennial Report of the Board of Agriculture, for 1885–'86, St. John discusses the geology of southwestern Kansas, and describes the gypsiferous Red Beds as probably Triassic. The formation is stated to be 300 feet thick, with a layer of massive gypsum near the top 15 feet thick, and the rocks dip slightly to the southwest.

19. Page 501.

Reports of Cragin.

Professor Cragin devoted considerable time to a study of the gypsum deposits in the southern part of the state, and in 1885[20] gave the following description:

"Heretofore the expression, gypsiferous horizon of Kansas, has been applied to the horizon of Permo-Carboniferous deposits, but Kansas has two important distinct gypsiferous formations, one Paleozoic and the other Mesozoic. The latter is represented in Barber and southeastern Comanche counties by a stratum of gypsum 12 to 20 feet thick, and practically continuous over an area of about 500 square miles."

The age is given as Benton, and the deposit was regarded as due to the evaporation of a large saline lake without an outlet.

Later Cragin[21] from further study concluded that this gypsum deposit resulted from evaporation in a great gulf or "Mediterranean Sea," and the age was given as Dakota.

Reports of Hay.

The late Robert Hay[22] in 1890 investigated the geology of the Gypsum Hills of Barber county. After describing the sandstone and shales at the base, he states that

"In ascending, we see the red rock gives way frequently to seams of selenite and laminated layers of greenish sandstone. But the sandstone and satin spar are ripple marked. The top reached, we find all these pinnacles and buttes are remains of another plateau, whose floor was solid gypsum, which stretches away to south and west, broken by broad valleys and deep canyons, reappearing beyond the Cimarron on Canadian and Red rivers and on edges of the Staked Plains."

He gives the following section:

Upper red rock above gypsum plateau	100 feet.
Gypsum series (massive gypsum and selenite seams)	200 "
Lower red rock (mainly without selenite and gypsum)	250 "
Total	550 feet.

The age is given as Triassic, and the salt deposits of the Cimarron valley are regarded as above the Triassic.

In his paper entitled "Geology of the Kansas Salt,"[23] Hay states

20. "Notes on the Geology of Southern Kansas," Bull. Washburn College Lab. of Nat. Hist., Vol I, No. 3, p. 85 and ff., 1885.

21. "Further Notes on the Dakota Gypsum of Kansas," Bull. Washburn College Lab. of Nat. Hist., Vol. I, No. 5, pp. 166-8, 1886.

22. "A Geological Reconnaissance in Southwestern Kansas," Bull. U. S. Geol. Survey, No. 57, pp. 22-25, 1890.

23. Seventh Biennial Report of State Board of Agriculture, p. 83 and ff., 1889-'90.

LONE MOUND, GYPSUM HILLS, SOUTHWEST OF MEDICINE LODGE.

Photographed by Grimsley, 1897.

VIEW IN GYPSUM HILLS, NEAR LONE MOUND, SOUTHWEST OF MEDICINE LODGE.

Photographed by Grimsley, 1897.

that at the base of the Permo-Carboniferous there is a well-marked gypsum horizon which is seen in wells at Fort Riley and on Clarke's creek in Geary county. He notes the deposits of the Blue river, at Hope and Gypsum City, and on Mill creek, in Washington county, 90 feet below the Dakota sandstone. He also states that a hard gypsum, locally called marble, is found near Geuda.

The southern Kansas gypsum deposits are described as follows:

"There is another great gypsum horizon in Kansas. It lies high up in the Red Beds. Its most marked exposure is in the Gypsum Hills of Barber county. Its surface is partly eroded, and in such places it is from 5 to 10 feet thick; but where the upper Red Beds are still upon it the gypsum of the best saccharoidal texture is 18 feet thick. The shales of the Red Beds for a hundred feet below are impregnated with gypsum, glisten with selenite, and are streaked with satin spar. This horizon stretches away west into Comanche county, and again shows itself in Clark. In the Indian country it is even thicker than in Kansas. In lonely ravines it shows itself in the faces of perpendicular bluffs or caps the ridges of promontories—everywhere a great white fact to front the sun. Owing to its elevation and the thickness of the bed and its lack of cover, it can be worked in Barber county to great advantage, and Medicine Lodge has already its plaster factory. With increased railroad facilities a great industry will be developed, for the raw material is as good as any in the world, and with the experienced management now operating, the best products of gypsum will be made here. Some forms of fine plaster, such as dental plaster and the kinds known as Keene's and Robinson's cements, are now successfully made, which hitherto were not supposed could possibly be manufactured out of England or France."

In 1892 Hay[24] devoted considerable space to gypsum in his paper on the "Geology and Mineral Resources of Kansas." He placed the northern Kansas deposits in the Permo-Carboniferous, and he was the first geologist to describe the secondary gypsum dirt deposits of central Kansas. In a brief paragraph on these deposits, he gives their origin as due to the wash of adjacent deposits of gypsum, clay, limestone, and sandstone.

Classification of Cragin.

Professor Cragin,[25] in a recent article on the Permian system in Kansas, gives an admirable description of the Medicine Lodge

24. Eighth Biennial Report of State Board of Agriculture, pp. 8-12 and 46-48, 1891-'92.
25. Colorado College Studies, Vol. 6, pp. 1-54, 1896.

gypsum horizon of southern Kansas. His section of the formations is:

Kiger division	250 feet.
Cave Creek formation	50 "
Flower Pot shales	150 "
Cedar Hills sandstones	75 "
Salt Plains measures	155 "
Harper sandstones	650 "
Total	1330 feet.

The Kiger division includes the Red Beds that lie above the Medicine Lodge gypsum. The Cave Creek formation, near Medicine Lodge, consists of a single statum of massive gypsum, called the Medicine Lodge gypsum, but on Cave creek, in Comanche county, the lower portion is the Medicine Lodge gypsum, 30 feet thick, and separated by the Jenkins clay, 10 feet thick, from an upper or Shimer gypsum, 10 feet in thickness.

The Flower Pot shales, as seen in the Gypsum Hills near Medicine Lodge, are variegated gypsiferous clays, with an interlacing selenite network. The Cedar Hills sandstone, found near the base of the Gypsum Hills, is about 50 or 75 feet thick. The Salt Plains measures are found in the southern part of the state and northern Oklahoma, and abound in salt plains, salt marshes, salt licks, and the like. The Harper sandstones form the lowest and thickest division and consist of red shales and sandstones.

The caves and natural bridges resulting from the solution and erosion of the gypsum in the western part of Barber and eastern part of Comanche counties are carefully described. The gypsum belt of southern Kansas, Oklahoma and Texas is stated to be one of the greatest in the world. The formations are placed in the upper portion of the Permian and called the Cimarron series. In this paper no reference is made to the origin of the deposit.

The northern and central Kansas gypsum deposits are placed in Cragin's Geuda measures, equivalent to the Marion of Prosser, though exception is taken to the latter name. The gypsum outcrop at Salina, called the Greeley gypsum, is placed 100 feet above the Hope gypsum, found near Hope and Gypsum City.

Report of Prosser.

Professor Prosser devoted much time to a study of the Upper Permian deposits of Kansas and has published the results of his investigations in Volume II of the Reports of this Survey.[26] He could find no break between the Wellington shales and the overlying Red Beds, but there was a marked unconformity between the latter and the overlying Cretaceous or Tertiary. He provisionally assigns the Red Beds to the Permian and adopts Cragin's name of the Cimarron series.

On account of the difficulty in tracing the various subdivisions of Cragin over any great distance only the prominent ones are retained, and he gives this classification:

Upper Permian ? { Cimarron Series. { Kiger formation. / Cave Creek gypsum. / Salt Fork formation.

The Salt Fork formation includes the lower part of Cragin's section mentioned above, namely: Harper sandstones, Salt Plains measures, Cedar Hills sandstone, and Flower Pot shales. The Cave Creek gypsum is the same as Cragin's Cave Creek formation, and Kiger includes the formations above to the Comanche series.

Prosser reviews at some length the literature concerning the Red Beds, and states that as no fossils have been found to settle the age, the beds cannot be satisfactorily correlated with Trias or Permian. The Red Beds have been looked upon as a single formation; but on account of the prominence of the Cave Creek gypsum in southern Kansas and Oklahoma it is regarded as entitled to rank as a formation, and so is used to separate the lower or Salt Fork division from the upper or Kiger formation.

Doctor Williston[27] regards the Red Beds as Triassic, and Mr. Vaughan,[28] of the U. S. Geological Survey, calls them Permo-Trias.

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26. "The Upper Permian," Vol. II, University Geological Survey of Kansas, p. 75 and ff., 1897.

27. Kans. Univ. Quart., Vol. VI, p. 56, Jan. 1897. [Recently Doctor Williston has obtained vertebrate fossils from the lower Red Beds in northern Oklahoma, near the Kansas line, which tend to make him look upon the Red Beds as being Permian. At this date he is still partially undecided, and therefore has not yet published his views on the subject. Personally he told the writer that the indications now favor the Permian age of the Red Beds.—E. H., Dec. 1898.]

28. Science, N. S., Vol. V, p. 559, April 2, 1897.

Geology of Kansas Gypsum.

The oldest geological formation in the state of Kansas is the Mississippian or Subcarboniferous series of rocks, covering a few square miles in the southeastern corner of the state. Then follow the coal-bearing strata or the Carboniferous, covering all the eastern part of the state, and consisting of sandstone, limestone, shale, and coal; and over this series, through the middle part of the state, rest the Permian strata.

All of these formations are of great economic importance, and they add very much to the resources of the state, comprising nearly all the mineral wealth. In the Mississippian formation are found rich caves and veins of lead and zinc of superior quality. In the Carboniferous occur the various forms of stored heat energy which are so very closely connected with the progress of this century. In this series are found the solid fuel, or coal; the liquid, or oil; the gaseous, or natural gas. In the Permian are found the large deposits of salt, gypsum, and clay.

In Europe the Permian is separated, in very many places, from the Carboniferous by broken and crumpled rocks showing great disturbances in the strata, but in North America the story is different. In this country the Permian follows the Carboniferous with a gradual transition in rocks and life forms, so that it has been very difficult to assign any lower limit; and in order to avoid troublesome discussions many writers have called the uppermost Carboniferous and the Permian beds, Permo-Carboniferous. This name is still applied to the formation in the east, but through Nebraska, Kansas, Oklahoma, and Texas, the Permian is better developed and of greater extent and thickness. In this area attempts have been made to separate the Permian from the Carboniferous.

The series in the Appalachian mountain region is without much doubt Lower Permian. West of the Mississippi river the Permian series, as separated from the Carboniferous, is much thicker, and reaches 2000 feet in Kansas and 5000 feet in Texas.

Kansas has been noted, not only as a battle ground in the history of social and political problems, but also in the history of

geological questions, especially concerning the presence and limits of the Permian. Professor Swallow[29] was the first to annouce and publish a notice of the occurrence of Permian rocks and fossils, which he did in the year 1858.

Since that time the problems of the Permian in Kansas have been carefully investigated and described. Our knowledge has been greatly increased by the work of Swallow, Hawn, Meek, Hayden, Newberry, Mudge, Hay, Cragin, and especially by Prosser.[30]

KANSAS PERMIAN GEOLOGICAL SECTION.

Prosser's[31] section of the Kansas Permian is as follows:

Cretaceous (in part.)	Dakota.
Upper Permian	Cimarron or Red Beds. Wellington (gray and red shales and clays). Marion (shales and limestones).
Lower Permian	Chase (shales, limestones, and flints). Neosho (shales and limestones).
Upper Coal Measures (in part.)	Cottonwood (limestone and shales). Wabaunsee formation.

The Cottonwood limestone is taken by Prosser as the line of division between the Carboniferous and Permian, because of the change in fauna and the constant character of the limestone.

"Its line of outcrop, frequently marked by a row of massive light gray rectangular blocks filled with *Fusulina cylindrica* and capped by a yellowish shale in which occur immense numbers of *Chonetes granulifera*, *Athyris subtilita*, *Productus semireticulatus* and a number of other fossils, constitutes one of the most distinctive formations yet seen in the upper Paleozoic rocks of Kansas and is very valuable for the purposes of stratigraphic and areal geology."[32]

The Kansas gypsum deposits of economic importance are found in the Permian system as outlined above. The gypsum of the northern area, in Marshall county, belongs to the Neosho division, which there consists mainly of sandy shales with several strata of fossiliferous limestones. The gypsum horizon is a few feet above the Cottonwood limestone.

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29. Amer. Jour. Sci., 2d series, Vol. XXV, p. 305. quoted by Prosser in Jour. of Geol., Vol. III, No. 6, p. 684, 1895.

30. For review of this work, see Prosser's Classification of Upper Paleozoic Rocks of Central Kansas, Jour. of Geol., Vol. III, Nos. 6 and 7, Chicago, 1895.

31. Loc. cit.; also see University Geological Survey of Kansas, Vol. II, pp. 51-93, 1897.

32. Journal of Geology, Vol. III, p. 704, Chicago, 1895.

The gypsum in the central area lies higher in the Permian, in the Marion shales and limestones, which are covered by the red Dakota sandstone, as does also that to the southeast in the vicinity of Mulvane and Geuda Springs.

In the southern or Medicine Lodge area the gypsum is found in the red, sandy shales of the Red Beds, which are probably Upper Permian. There is no break or unconformity between them and the lower lying Permian, and they are covered unconformably either by Cretaceous strata, or by Tertiary gravels.

The deposits of gypsum, therefore, rise geologically from north to south, but they are confined to the Permian formation. The deposits to the south in Indian Territory, Oklahoma, and Texas, have been placed in the Permian, while those at the north in Iowa are referred to the Cretaceous.

STRATIGRAPHICAL RELATIONS.

Northern Gypsum Area.—The gypsum deposits of northern Kansas rest on a nearly level floor of limestone which dips toward the west at a low angle. The gypsum stratum is solid and not laminated, and it is traversed by irregular branching clay seams. The upper surface of the gypsum is very irregular, showing that much of it has been removed since its first formation. This was done before the consolidation of the overlying shales, for they are horizontal and are not folded to conform to the irregularities. This uneven surface is shown in all the mines, but perhaps best in the Great Western mine, where the gypsum for 200 feet lies in rounded masses with the long direction parallel to the hill slope.

The water channels so well shown in the Winter mine, and the cutters or veins with their beautiful transparent crystals in the Fowler mine, show that water solution has produced marked effects in the later history of the deposits, effects which are even now in operation. The underground circulating waters have dissolved the gypsum, forming channels, and have redeposited much of the substance in the fissure in the form of transparent crystals, or near the top in the form of needles of satin spar.

A glance at the map of the area shows that a very large quan-

tity of the gypsum has been carried away by stream erosion, a destructive erosion which has revealed the store of mineral wealth in these hills in the sections along their banks. No traces of salt were found near the gypsum rock.

The geological sections show that the gypsum occurs about 20 feet above the Cottonwood limestone, which is taken by Prosser as the base of the Permian, so that the gypsum comes at the base of the Neosho division outlined in his paper.

The gypsum is 8 to 9 feet thick and rests upon limestone underlaid by sandy shales. It is covered by non-fossiliferous sandy shales, with limestones containing Permian fossils and flint nodules, 50 and 100 feet above the gypsum. The cover of compact shales has served to protect the underlying gypsum from solution by circulating water to a considerable extent, thus explaining the absence of the marked erosion and solution effects noted in the areas farther south.

Central Gypsum Area.—In the central area the gypsum rock rests upon shales, and dips toward the west. Its thickness is somewhat greater than in the northern area, reaching 14 feet, and it is covered by sandy shales. In the central part of this area the gypsum is compact, and in the lower portion contains the small selenite oval crystals which give the rock a spotted appearance. In the upper portion it is often filled with more or less irregular dark streaks which give a banded appearance.

At the Solomon mine the gypsum layers are intercalated with beds of shale, giving a distinctly stratified appearance to the whole series. Abundant traces of salt occur in springs and wells near the Solomon river, but no salt is associated directly with the gypsum. Just to the southwest of the gypsum area, in the Hutchinson-Kingman-Lyons region, occur the large salt deposits, which have placed Kansas in the first rank of salt-producing states of the Union.

The Dakota red sandstone forms the top of the hills south of Gypsum City and nearly 300 feet above the lower gypsum horizon, so the gypsum of Saline and Dickinson counties belongs to the Marion formation of the Permian. The salt beds mentioned above come higher in the Permian, though found at a

topographically lower level in the direction of the dip of the gypsum rocks.

The shales and gypsum in the Smoky Hill river region are irregularly folded and broken, as a result of settling, possibly by the leaching out of former salt beds and part of the gypsum. The salt water may have percolated downward, to rise again in the salt springs of that region.

Southern Gypsum Area.—The southern Kansas gypsum, 20 to 50 feet thick, extending into Oklahoma and Texas, is found in the Red Beds. Near Medicine Lodge it forms the cap of the hills, but further west it is covered by red sandy shales, and the same kind of shales are found everywhere below the gypsum. Strata of sandstone of varying thickness are seen in the shales below, and the base of the Gypsum Hills consists of a heavy stratum of sandstone. Some of the sandstone is ripple marked, giving evidence of shallow water conditions.

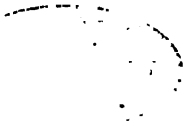
The entire series of shales, sandstones, and gypsum is very uniform in character through the whole region. The gypsum is not broken by clay seams, and is compact and remarkably pure. The shales below contain selenite and satin spar layers running in all directions, forming a network. A short distance below the solid gypsum occurs a layer of sand and gypsum nodules cemented together by gypsum, forming a very enduring layer of greenish color, which projects from the hillsides and can be readily traced throughout the region. The dip of the strata is slight and somewhat irregular, but it appears to be mainly south or southwest and the deposit thickens in that direction.

The caves, natural bridges, and the irregular upper surface of the gypsum, as well as the selenite layers in the shales below, give evidence of great removal through solution. A salt deposit occurs to the southwest in the Salt Plains district, but no trace is found close to the gypsum.

Small deposits of gypsum are found between the northern and central areas, and a few between the central and southern areas. In age, the gypsum deposits are older at the north and younger to the south. In level above the sea, the deposits are lower at the north and higher toward the south.

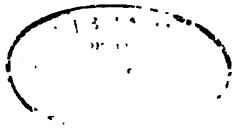
MANSARD HILLS, IN RED BEDS, NEAR MEDICINE LODGE.

Photographed by C. S. Prosser, 1896.



FLOWER-POT MOUND, RED BEDS HILL, NEAR MEDICINE LODGE.

Photographed by C. S. Prosser, 1896.



CHAPTER IV.

KANSAS GYPSUM MINES AND MILLS.

Blue Rapids Deposits.

The first gypsum deposits worked within the state of Kansas were in the northern or Blue Rapids area. In November, 1869, the commissioners laid out the site for the town of Blue Rapids. They carefully investigated the natural resources of the region and recognized the value of the water-power of the Blue, and also the value of the gypsum deposits which had been known for some time to exist on the Big Blue, about two miles northwest of the town. On selling their various properties they made a reservation along the Blue of 100 rods, including the known outcrop of the beds and extending back from the river for a distance 320 feet.

About the year 1871 Mr. J. V. Coon, of Elyria, Ohio, came to the new town, and, as the story goes, he burned some of the gypsum and carried it back to Cleveland, where it was pronounced to be of good quality, and two car-loads were ordered at a good price. He and a brother returned to Blue Rapids in 1872 and built a frame shed on the east bank of the river, below the town. In an iron kettle, which held about five barrels and which was heated by a stove, they commenced the manufacture of plaster of Paris. Prosperity seems to have attended their work, for in 1875 a stone mill was built by Coon & Son on the west side of the river, and the water power of the river was now used for grinding. This mill is still standing, a monument to the commencement of a great Kansas industry. The town, for purpose of encouragement of the new departure, granted them the north half of their reservation, described as extending from

a point at the middle of the outcrop, and thence north. This mill was operated for nearly twelve years, and then the firm unfortunately failed. The mill property and the gypsum grant of fifty rods of outcrop and twenty rods back in the hill came into the hands of Mr. Sweetland, a business man of Blue Rapids. It was leased to several parties, and the mill was run to the year 1889, when the flood of that year caused considerable damage, resulting in the abandonment of the mill.

Mr. Hayden, of New York, in 1887 bought the remaining portion of the old reservation and the adjoining Robinson farm. Fowler Brothers bought the farm, back of the Sweetland twenty rods limit.

The earlier mining was done by stripping the cover of dirt and shales, and the rock was hauled in wagons to the mill. Later it was brought down the river in flatboats drawn by a small steam tug.

FOWLER'S MINE.

In 1887 the Fowlers formed the Blue Rapids Plaster Company and built a one-and-one-half-story frame mill of one kettle capacity on the west side of the river at the edge of town. The present entry to their mine is fifteen feet above the water level, though the gypsum bed-rock is the bed-rock of the river, which is 4 feet deep at this place. The entry runs east about 350 feet and the gypsum dips west toward the river. Five men are employed at the mine, and the rock is hauled out and up an incline to the railroad, where a twenty-five ton car is loaded in two days and hauled to the mill.

The gypsum occurs as a gray mottled rock with saccharoidal or sugary texture, breaking with irregular fracture. It is more or less crystalline, showing fibres and plates. Near the upper surface the tendency to crystallization is seen in the dark, irregular plates which characterize that portion of the stratum. The top consists of a layer of white selenite needles forming satin spar with a thickness of one-fourth to one and three-fourths inches. These stand vertical and are slightly curved, and they appear to be oriented with the dark plates below. A similar layer of satin spar is found on the lower surface of the

layer. The rock is irregularly traversed by blue clay seams which contain a small amount of carbonate of lime. These are not large nor numerous enough to injure the rock for plaster, and in some parts of the stratum they are absent. On exposure to the air for some time or when crushed, the rock becomes very soft and snow white.

In this Fowler mine cutters or veins occur which contain masses of transparent selenite crystals grown together, varying in size from the very smallest to those of several inches in length. This is the only mine in the state which yields crystals and it is especially interesting on that account.

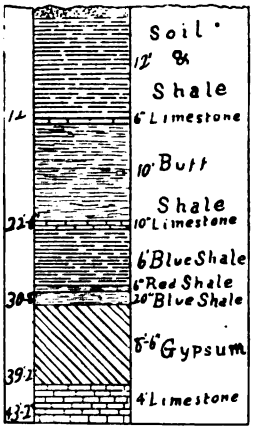


FIG. 1. Geologic Section at Fowler's Mine, Blue Rapids.

The section at this mine, figure 1, shows a blue limestone bed-rock over 4 feet thick. Above this comes the gypsum with an average thickness of 8½ feet, covered by 8 feet of red and blue shales, followed by a thin limestone layer and then 22 feet of buff shales with a thin stratum of shaly limestone about the center. On the hills to the east of Fowler's the buff limestone, which occurs throughout the region, outcrops 100 feet above the gypsum. This mine, which was located on the original gypsum grant of the town company, represents the oldest gypsum working in the state, and gypsum has been taken out from there almost continuously since the days of Coon & Son, though never on a very large scale.

GREAT WESTERN MINE.

The Great Western mine is located on the side of a bluff one mile north of the town of Blue Rapids and about 50 feet above the level of the water in the river at the railroad bridge. It is two and one-fourth miles southeast of the Fowler mine. The

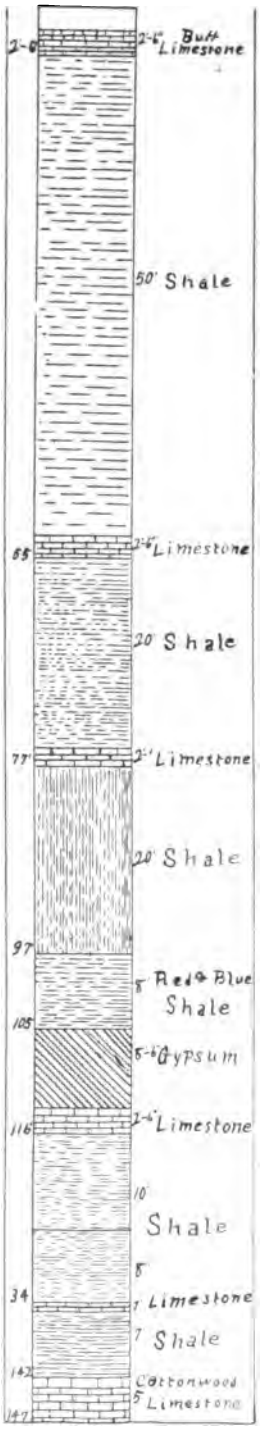


FIG. 2. Geologic Section at Great Western Gypsum Mine, Blue Rapids, showing Relation of Gypsum to Cottonwood Limestone.

entry runs east of north and goes into the hill 400 feet. In the first 200 feet the gypsum was in rounded masses, thick at the middle and running out on the sides, with the trend across the entry and parallel to the slope of the hill, or south-east-north-west. The channels between these rounded masses appear to be old water courses. Two of the channels which have been explored in this mine for a distance of 200 feet are clearly water courses, and have on their floors a deposit of sand and mud.

The section of the mine and hill above, Figure 2, shows 8½ to 9 feet of gypsum resting upon a brown crystalline limestone, and covered by 8 feet of red and blue shales similar to the Fowler mine. Over these shales there is a series of buff shales with two buff limestones 20 and 40 feet above the gypsum. The hill which rises 100 feet above the gypsum is capped by a buff fossiliferous limestone 30 inches thick, in three courses, and carrying a considerable amount of flint.

A section one mile to the east of this mine, shown also in Figure 2, in a small ravine, known as Lovers' Nook, where

the water falls over a limestone ledge, Plate XII, shows 3 feet of blue shales at the bottom, covered by 4 feet of buff limestone in two courses, filled with the small shells of *Fusulina cylindrica*, or the wheat-grain fossil as it is commonly termed. Over the limestone 3 feet of shales are filled with fossils of the species *Seminula argentia, Chonetes granulifera, Productus semireticulatus, Derbya crassa*, crinoid stems and other forms. Above the fossiliferous shales are found 15 feet of buff non-fossiliferous shales and thin limestones. This lower stratum is the Cottonwood limestone, covered by the Cottonwood shales marking the summit of the Carboniferious series in Kansas. The top of the *Fusulina* limestone is about 30 feet (by barometer) below the bottom of the gypsum at the Great Western mine. The lime rock is quarried for building stone near the Union Pacific depot at Blue Rapids, and it is found in other ravines, always below the gypsum, so that the latter is of Permian age, according to the accepted classification of the Kansas rocks already outlined in this paper.

The gypsum rock at the Great Western mine possesses the same sugary texture as the rock at Fowler's and resembles it very closely. There is, however, a striking difference in the absence of the cutters and perfect crystals. The satin spar layer on top is usually thicker than at Fowler's. The company has applied the name of *crystal rock* on account of its loose texture and brilliant surfaces when placed in the light. The rock is hauled in small cars over an elevated platform to the upper portion of the mill, which is on a level with the mine entry, as shown in Plate XIII.

WINTER'S MINE.

On the bank of the Little Blue, two miles west of Blue Rapids, is located the Winter mine, shown in Plate XIV. The rock was formerly obtained by stripping and a very considerable area was thus worked out, but as the cover became thicker back from the river it was thought to be more economical to mine by running an entry into the hill. This entry is about 15 feet above the level of the water, and runs east about 900 feet into the hill. The double-entry system of mining is used, with

rooms sixteen feet square. In the mine there is a water course which runs south of west, and in its vicinity the roof dips down into the gypsum rock almost cutting it out. Twenty-five men are employed at the mine and mill and forty to fifty tons of rock are taken out in a day.

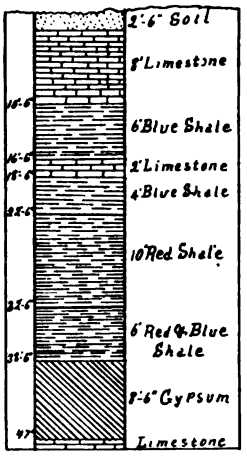


FIG. 3. Geologic Section at Winter's Mine, Blue Rapids.

A section at the mine, Figure 3, shows a compact limestone floor on which rests the gypsum layer 8 to 9 feet in thickness. This is covered by about 10 feet of red and blue shales, and two limestones of 2 and 3 feet thickness separated by 11 feet of shales and shaly limestone. The gypsum rock is similar to the other exposures already described, and the cutters and crystals are absent.

OTHER EXPOSURES.

Gypsum is reported in the various wells to north, south, and west of Blue Rapids, but appears to be absent in the wells to the east. The stratum is probably continuous over a large area around Blue Rapids. It is reported in wells at Herkimer, west of Marysville, at 80 feet below the surface. On the Axtell farm, three miles north of the Great Western mine, it was struck at 90 feet below the surface. It was found on the Lee farm, west of Blue Rapids, and three-fourths of a mile south of Winter's mill, at 60 feet below the surface. Gypsum is reported in many other wells, though it is not always possible to tell how much reliance can be placed upon the reports, which are often based upon peculiar taste of the water, which might be caused in other ways. The evidence, however, shows a large gypsum area, though the actual outcrop along the streams is small, as shown on the map. Plate II. This is caused in part by the soft char-

acter of the gypsum and shales, so that the rock is dissolved out and covered by the crumbling debris from above.

On the Yarrick farm one mile south of the town is a mine from which a small amount of gypsum was removed some years ago. The blocks which are piled around the entry are now badly weathered and bleached out so as to present a clear white color, and fissured with small seams. The fresher specimens show that the gypsum is about the same as in the other mines. The rock is 100 feet below the buff limestone on the hill above.

Gypsum occurs in the shales in many of the ravines to the west of Blue Rapids, especially near Waterville, in the form of rounded nodules pink in color. At this last locality the nodules occur in a black shale of which 2 feet are exposed, and overlaid by 3 feet of blue shale and a 30-inch stratum of limestone. One hundred feet above is the buff limestone with flint nodules, which may be traced across the country. The gypsum lies about ten feet above the water in the Blue river.

A similar exposure was noted on the John Morrow farm, about two miles east of Waterville or two miles west from Blue Rapids. At this place the pink gypsum nodules are imbedded in 12 feet of shales and near the water's edge. Above comes 20 feet of red and blue shales and limestone.

The dip from Winter's mine to Fowler's, one and one-half miles north, is 12 feet, or 8 feet to the mile; and from the Yarrick mine to the Great Western, a distance of two and one-half miles a little east of north, the dip is 18 feet, or 7 feet to the mile. The dip from the Great Western to the Winter mine, a distance of two and one-half miles west, is 18 feet, or 7 feet to the mile. The dip of the gypsum, then, in the vicinity of Blue Rapids is about 10 feet to the mile to the northwest. The dip from the Great Western mine to the exposure at Waterville is between 8 and 10 feet to the mile.

Gypsum City Deposits.

There are two well-marked gypsum rock horizons in the central Kansas area and indications of a third. The lower and more extensive deposit extends over the central, northern, and

western portions of the area; the second one over the central and southern part; and the third is found only in the southern part. The interval between the middle and lower deposits is 100 feet, and between the middle and upper it is 40 feet. The dip of the gypsum is nearly west, varying from 6 to 12 feet to the mile.

SOLOMON MINE.

In the northern part of the area, six miles southwest of Solomon, on the bank of Gypsum creek, is located the mill and mine of the Crown Plaster Company, shown in Plate XV. A section of the hill at the mine, represented in Figure 4, shows 40 feet of shales and gypsum. The mine entrance is 15 feet above the water in the creek, and the stratum worked is 5 feet thick, underlaid by about 4 feet of shaly limestone. Below this there is a series of shales with a 3-foot stratum of gypsum. The roof of the mine is a compact, dark shale with a thickness of 3 feet. Above this come 2½ feet of buff shales and 2 feet of gypsum. There is an alternation of shales and gypsum to the top of the hill. The shales with the intercalated gypsum layers are folded and broken. The folds extend down into the mine, causing the shales of the roof to cut out the gypsum in many places, so that the mine has now, in 1898, been abandoned. The dip of the gypsum is north, toward the creek.

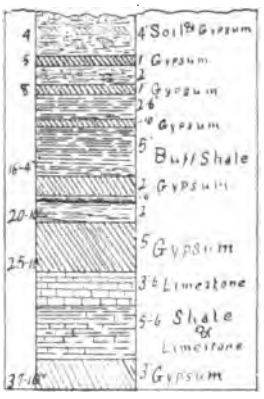


FIG. 4. Geologic Section at Solomon Gypsum Mine.

The lower part of the heavier gypsum layer is very compact and filled with oval crystals of yellowish brown selenite, having the greater length in the direction of the vertical crystal axis. The crystals are laminated by the pronounced pinacoidal cleavage. The larger ones are about seven-eighths of an inch long and half an inch wide, and rock specimens from this portion of

COTTONWOOD LIMESTONE, AT LOVERS' NOOK, TWO MILES NORTHEAST OF BLUE RAPIDS.

Photographed by Grimsley, 1897.

GREAT WESTERN CEMENT PLASTER MILL, AT BLUE RAPIDS.

Photographed by Grimsley, 1897.

the stratum break with a conchoidal fracture. The upper part is white, less compact, contains no oval crystals, and pieces break more irregularly.

The occurrence of these selenite phenocrysts is of no little interest, as it indicates something regarding the physical conditions under which they were formed. The frontispiece, and also Plate XVI, shows the general appearance of the massive gypsum with the selenite phenocrysts included, while Plate XXVIII shows a number of detached crystals with their rounded edges. The hand level in Plate XVI is $6\frac{3}{4}$ inches long, from which the size of the crystals can be judged. The crystals shown in Plate XXVIII are natural size.

The existence of such phenocrysts indicates that the ocean water at one time was evaporated very slowly, and under the most favorable conditions for the production of individual crystals. Later there was a slight freshening of the water by surface drainage entering the concentrated lake, so that a partial redissolving of the crystals was effected, as shown by the rounded edges of the crystals. Still later there was a rapid evaporation of the water, precipitating the massive gypsum, and an agitation of the shallow water sufficiently vigorous to mix the crystals already formed thoroughly with the new precipitated gypsum, forming the whole mass as it now appears. We have here, therefore, a record of rains and winds not unlike those now common to the same locality.

HOPE MINE.

At Hope, twenty miles southeast of Solomon, is located the mill of the Kansas Cement Plaster Company, which has been in operation since 1887. They first used the middle stratum, quarried near the top of the hill, one and one-half miles west of town. The rock is about 5 feet thick, and lies 10 feet below a buff, shaly limestone. The gypsum is white and compact in texture, except near the surface, where it is rendered granular and more or less colored as a result of weathering. The satin spar associated with it is of clear white color when viewed from the side, and viewed from above it possesses a cream-

white tinge. Over the gypsum is a thin deposit of black, impure, shaly gypsum.

In 1894 the company abandoned this quarry, and sank a shaft a quarter mile west of the quarry, 80 feet in depth, to the lower stratum, which is nearly 14 feet thick. The rock is white, though much of it is traversed by wavy dark lines which lie close together, giving an appearance somewhat like granite or gneiss, so that plaster made from it is called by the company "granite cement plaster." The lower part of the stratum is compact, and contains rounded crystals of selenite, with dark mottled surfaces. It thus bears a close resemblance to the Solomon gypsum, already described, although the crystals are usually large, averaging about two inches by one. These are the only two localities in this central area where the gypsum rock is used for plaster.

A study of the levels and character of the rock indicates that the gypsum quarried below Solomon City is the same as that in the shaft near Hope.

The gypsum in the quarry on the hill east of Hope lies below a buff, soft, shaly limestone, and this limestone accompanies all the gypsum outcrops to the south and southeast —at the Henquenet cave, German church, Rhodes mill, Banner City. The horizon is 100 feet above the Hope shaft rock. The levels and dip would connect this upper layer with the outcrop near Salina, which was named by Cragin[33] the "Greeley gypsum," from the township in which it was found. He states that it was probably 100 feet higher than the Hope gypsum, but as two gypsum horizons occur at Hope it is doubtful to which one he refers. The level at the Salina gypsum is 1250 feet, and along Gypsum creek, four miles east, is 1230 feet at the gypsum horizon, showing a dip of 4 feet west. The level at Hope quarry, 26 miles southeast of Salina locality, is 1400 feet, making a dip of nearly 6 feet to the mile, which corresponds very nearly with the dip from Gypsum creek to Salina and to the dip of the gypsum throughout the central area.

33. Colorado College Studies, Vol. VI, p. 10, 1896.

OTHER EXPOSURES.

The lower gypsum horizon which, for convenience of description, may be called the Solomon gypsum, outcrops a quarter of a mile south of the Dillon mill, where a section of 5 feet of rock is exposed, covered with 5 feet of dirt. This locality is two miles west of the Hope shaft and the rock is 10 feet lower. Fifteen miles west of the Dillon outcrop, in a well near the Tinkler earth deposit at Gypsum City, rock gypsum is found 60 feet lower. This same gypsum rock outcrops along the east bank of Gypsum creek, with about 3 feet of white granular gypsum exposed. It may be seen at various places along the north and south line from Gypsum City to Solomon, and at nearly the same levels. Similar outcrops are found in the Holland creek area. South of Gypsum City and west of Gypsum creek no trace was found of gypsum, either in outcrops or in wells. The upper gypsum, as exposed in the Hope quarry, is found on the higher levels to the west and north. It is found seven miles southwest, on the Henquenet farm, at the gypsum cave, shown in Plate XVII. The entrance to this cave trends southwest and it has a hight of 3 feet, with the same breadth, but soon narrows. This cave has been followed for several hundred feet, and so was explored by a number of men. It has attracted much interest among the people of that region, on account of a local tradition that large sums of money and valuable treasure were stored in it by a band of robbers. So far, this hidden treasure has been undisturbed, though each year new adventurers vainly seek the unknown golden nook.

The lower 8 feet of the gypsum is veined and spotted, and the polished slabs bear some resemblance to onyx, while the upper 2 feet exposed is fine grained and compact, like alabaster. This layer is covered by 15 feet of shales and 10 feet of the buff shaly limestone. A small stream flows into this cave after heavy rains, and the outlet is not known. This cave is continued eastward for sixty feet as a ravine, with gypsum walls, while the roof has caved in and for a considerable distance has been removed. No other caves are found in this region, but

there are a number of similar ravines which probably have the same origin.

Experiments which are apparently successful have been made in hardening this banded gypsum for interior finish. The owner of the cave hopes soon to establish a business devoted to the manufacture of gypsum finish.

Two miles west of the cave, near the top of the hill, there is an exposure of 15 feet of white gypsum which, according to barometric measurements, is about 30 feet higher than the cave gypsum. One mile further west a deposit of banded gypsum covered with buff shales was found in a well on the Wuthnow farm. The well was drilled 8 feet into the rock and then abandoned. On the hill one-quarter mile to the north is an old gypsum quarry 35 feet higher than the gypsum in the well. The rock as exposed is 5 feet thick, dark colored and irregularly crystalline in the upper portion, and it is covered with a layer of black gypsum. This deposit and the one on top of the hill noted above were the only outcrops noted in the third or upper gypsum horizon.

In the well on the Rhodes farm, three miles west of the Wuthnow farm, the gypsum was found 40 feet lower than at the cave, six miles east and 60 feet lower than the Hope quarry, eight miles to the northeast. This layer outcrops at the same level in the ravine below the well, and it is compact and banded. Over it, is found the buff shaly limestone as at the other places. The dip from Wuthnow well gypsum to Rhodes gypsum is nearly 12 feet to the mile.

One mile south of Rhodes deposit the gypsum again outcrops, on the Banker farm, and is found for some distance further south. It also outcrops on the Tucker farm, one mile east, at a level nearly 15 feet higher. One mile northeast of this exposure is a heavy deposit of gypsum 10 feet higher, close to the German church.

The deposits of gypsum rock do not attract much attention through this central area, as the gypsum earth deposits are easier to work and are regarded as more valuable. The lower horizon, or Solomon gypsum, seems to be more favorable for

working than the Hope gypsum, since it holds good thickness and quality wherever found, while the Hope layer varies in different parts of the area. When the earth deposits are exhausted these rock deposits will again command attention and the rock will be quarried for plaster manufacture.

Secondary Gypsum Deposits in the Central Area.

At a number of places in the central Kansas area occur important secondary deposits of gypsum which form the basis of the greater portion of the plaster manufacture. The material is locally called "stucco," "gypsum dirt," and other similar names. It is a granular earth, found in low, swampy ground, dark colored in place; but on drying it assumes a light ash-gray color. It is soft, incoherent, so that it is readily shoveled into cars, and is ready for calcining with less labor and expense than is required in working the solid rock.

At the present time four of these deposits are opened in the central area, plaster being now made at three of them, a fifth is worked to the north in Clay county, and a sixth is opened to the south in the northern part of Butler county.

DISCOVERY AND EXTENT OF THE AREAS.

The first deposit was discovered in the spring of 1873 near Gypsum City, by Mr. John Tinkler, in running a fire-guard around a field. Two years later he calcined some of the earth in an ordinary thirty-eight gallon kettle and used the plaster in the cellar of his house, where it still remains good. In 1889 he with others formed the Saline County Plaster Company and built a mill at the edge of town. This was afterwards sold to the Acme Cement Plaster Company, but they no longer use the mill or deposit. In 1892, 7000 tons of plaster were sent from this mill to Chicago for the World's Fair buildings and a medal was awarded the company in recognition of the qualities of their plaster. It has been used in the government buildings at Forts Riley and Leavenworth, and the product has been shipped to all parts of the United States.

TINKLER DEPOSIT AT GYPSUM CITY.

The Tinkler deposit covers an area of twelve acres, and lies close to the surface with little or no cover. It lies in the valley of a small creek tributary to Gypsum creek. The maximum thickness is 17 feet, while the average is 8. The dirt was hauled in wagons to the mill, one and one-half miles away. The appearance of the deposit resembles very much a fine sand bed or loess formation, and there is a tendency to break in smooth planes or joints. Organic matter occurs through it, and underneath is a layer of clay, and below the clay is a deposit known as the *black gypsum*, regarded as worthless. Strong springs break through the deposit on the east side. The top of the gypsum earth is 20 feet above the water in Gypsum creek, a quarter of a mile to the west. In a well dug on the hill above the deposit rock gypsum of good quality was struck 30 feet down, or 20 feet below the top of the earth. No trace of gypsum was found in the hills above the earth deposit.

AGATITE DEPOSIT AT DILLON.

A number of years after the discovery of the Tinkler gypsum area, Mr. Gotlieb Heller discovered a similar deposit fourteen miles east, near Dillon station. He purchased the rights to the deposit from John Linden for $100 and a team of mules, and later it was purchased by the present owners, the Agatite Cement Plaster Company.

This deposit resembles that at Gypsum City. The area is at least forty acres in extent, and lies in swampy ground, near a small creek. Its greatest thickness is 18 feet. Plate XVIII represents the actual working of this deposit. It is covered to a slight depth with soil, and water in springs is very troublesome in working this deposit. Gypsum rock outcrops a quarter mile away at nearly the same level. This gypsum earth is taken out by aid of the plow and scraper, and after drying a few days in the sunshine is loaded into cars and hauled to the mill, one-half mile north, shown in Plate XIX.

ALUMINITE OR ÆTNA DEPOSIT NEAR DILLON.

Another similar deposit is located three and one-half miles southwest of Dillon, in a low place near a small stream, and here again springs prove troublesome. Plate XX shows the actual working of this deposit. The cover is 10 feet thick, and the deposit is 5 feet, but near the top is a layer of 20 inches of sand and gypsum, which sets too quickly, and so is thrown out. Gypsum rock is not reported below this, but a heavy deposit is found on the hill about 30 feet above the gypsum earth. The material from this deposit is hauled to the mill close by, and is the property of the Ætna or Aluminite Cement Plaster Company. Mingled with the earth were shells and some bones, which were thought by the finders to be buffalo bones. Unfortunately these have been lost and cannot now be identified.

ACME DEPOSIT AT RHODES.

In Marion county, about seven miles south of Banner City, the Acme Cement Plaster Company owns a mill and a gypsum earth deposit similar to the others, which is represented in Plate XXI. It is 6 to 10 feet thick, and is near a small creek. The gypsum rests upon sand, in which Professor Sharp found recent shells of types *Planorbis* and *Physa*. Eighteen feet below the top of the earth is a well-marked gypsum ledge. The actual working of this deposit is shown in Plate XXII. This mill has not been running since last spring.

AGATITE DEPOSIT AT LONGFORD.

The Agatite Company have another mill near a gypsum-earth deposit at Longford, Clay county, thirty-five miles northwest of the Dillon mill. This mill is shown in Plate XXIII. The deposit is near a creek four miles east of the mill, and varies from 2 to 10 feet in thickness over an area of sixty acres, and is shown in Plate XXIV. Other gypsum earth deposits are reported from this same region and near Manchester.

MICROSCOPICAL EXAMINATIONS.

These gypsum deposits undoubtedly belong to the earthy variety of gypsum, called by the Germans Gypserde, Himmels mehl; Himmels mjol by the Swedish, and Gipsowaya muka

by the Russians. These varieties are described as loose, slightly cohering, dust-like particles of yellow or gray color. Such deposits are found near Neustadt, in Saxony, near Frankenhausen, Bohemia, Norway, and near Paris. The material is thought to be identical with the *chaux sulfatee niviform* of Hauy. Its origin in these regions is ascribed to the solution of gypsum in water, and it is found often in fissures and is more abundant in wet than in dry seasons. At Frankenhausen, it was observed on the top of a gypsum mountain as a superficial stratum of about one and one-half feet thickness, not consolidated, and still containing water. Its main use in those regions was as fertilizer and whitewash. The name used in this report for these deposits is the translation of the German, or gypsum earth.

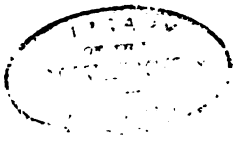
A microscopical examination of the central Kansas deposits shows a considerable uniformity in character, as represented in Figure 6. The earth is seen to consist of a mass of small, angular gypsum crystals of varying size. Perfect crystals are found, but most have the terminations somewhat rounded by solution. They are not transported crystals but have clearly crystallized in place. Mingled with the gypsum crystals are small quartz crystals, seen especially in the Clay county deposits. A considerable amount of poorly crystallized calcite is present, and also traces of organic material.

There is a small deposit of gypsum earth just east of the town of Hope, close to the Missouri Pacific track. This appears to be of good quality, though no use is made of it at the present time. In looking through the ravines to the west and southwest of Hope, small deposits of the earth are found in nearly all of them. These deposits are of shallow depth and limited extent, and are usually impure through the admixture of clay and soil.

The deposits are of economic importance only in especially favorable localities where the valleys broaden out and where swamp conditions are found. There are not many such places known in the state, and the largest ones are probably now located, but smaller deposits will be used after the larger ones are exhausted. Gypsum earth is a common product, and is

WINTER'S GYPSUM MINE, BLUE RAPIDS.

Photographed by Grimsley, 1897.



MERRILL GYPSUM QUARRY, ON GYPSUM CREEK, MARION FORMATION, SALINE COUNTY.

Photographed by C. S. Prosser, 1896.

found on nearly every farm in this central region. While most of these earth deposits will prove of small value, yet it will be some time before they are exhausted; and when this result is reached the deposits of gypsum rock will still make central Kansas an important plaster center.

Gypsum Deposits between Gypsum City and Medicine Lodge.

PEABODY AND ANNELLY DEPOSITS.

In 1885 the Peerless Cement Plaster Company built a mill on the farm of Mr. Dean, five miles west of Peabody. The mill was in operation about two years and then abandoned and the machinery sold. The rock was hauled from Liberty creek, one and one-half miles north of the mill, from section 34, East Creek township. There were 2 feet of good gypsum covered by 30 feet of dirt and impure rock, and underlaid by clay. The product is said to have been of high grade and was used throughout the neighborhood. A few years ago gypsum earth was discovered in this same area, covering fifteen acres on the Dean and Brown farms, with a maximum thickness of 7 feet. Gypsum outcrops along Liberty creek at a number of places. There was a mill at Furley, in northeast corner of Sedgwick county, which used gypsum rock found in that locality. At Annelly, in the southeastern part of Harvey county, gypsum of good quality was found in the wells at a depth of 30 feet, and the rock outcrops on Gypsum creek just south.

BURNS DEPOSIT.

Seven and a half miles southwest of Burns, close to Davis creek, in Butler county, Mr. Gottlieb Heller has opened a gypsum earth deposit which will average 6 feet thick over about two acres of land, and a lesser thickness over a much larger area beyond. The deposit is covered by a thin layer of soil, varying from 1 inch to 2 feet in thickness. Where Davis creek cuts through the gypsum the deposit is about 9 feet, and has a jointed structure, breaking out in large blocks. No gypsum rock is found in the region above this gypsum earth deposit, nor is any reported from the wells in that vicinity, so that as

far as is known there is none lying below the deposit. It is whiter in color than any of the other deposits known in the state. Under the microscope it is found to be almost entirely composed of minute yet very perfect crystals of gypsum of uniform size. These crystals are more perfect in form than any others which have been examined from the gypsum earth beds.

As no plaster has yet been made from this deposit it cannot be said whether or not this extra degree of purity will result in an extra plaster. As is pointed out later under the discussion of the technology of the gypsum plasters, the plaster made from the rock gypsum is slightly different in character from that made from the gypsum earth deposits, this difference being due principally to the greater purity of the gypsum rock. If the gypsum earth material makes a plaster more desirable in some respects than that made from the rock gypsum, it may be possible that a high degree of purity in the gypsum earth beds would result in the production of a plaster more nearly like that obtained from the rock gypsum.

A mill of two-kettle capacity has been erected, and began operation with one kettle early in December, 1898, with a prospect of starting the second kettle soon. This mill is erected at Burns, on the El Dorado branch of the Atchison, Topeka & Santa Fe railway. The mill is operated under the company name of "The Kansas Southern Cement Plaster Company."

MULVANE DEPOSIT.

About two and a half miles northeast of Mulvane, just across the line in Sedgwick county, a large deposit of the gypsum earth has been discovered on the farm belonging to Mr. W. R. Stubbs. The material covers an unusually large area along a little stream which cuts through the bed of the deposit, exposing it along the banks, where in places it reaches a thickness of 12 feet or more. It has been estimated that there is enough of the material here to produce nearly half a million tons of the manufactured plaster. The quality of the gypsum earth compares favorably with that found elsewhere, as may be seen by referring to the table of analyses.

A company has been formed to manufacture the plaster, and mills are in the process of construction which will probably be in operation by the 1st of January, 1899, operated under the corporate name, "The American Cement Plaster Company." The mills will be established at the mine, with a switch reaching the grounds from the Augusta branch of the Atchison, Topeka & Santa Fe railway. At present the head offices of the company are located at Lawrence, Kan.

GEUDA SPRINGS DEPOSIT.

About four miles northwest of Geuda Springs, in Sumner county, a large deposit of the rock gypsum has been known for nearly twenty years. It outcrops along the banks of a small stream on the west half of the southeast quarter of section 27, township 33 south, range 2 east. From this place rock gypsum was obtained for the erection of a large business block in Wellington, generally known as the "marble block." Cut in the form of stone, it presents a beautiful appearance, so that the building is one of the handsomest in that part of the state.

At the present time the surface covering of earth and soil has caved in to such an extent that it was impossible to determine the exact thickness of the gypsum beds. The local report is that they are known to be 15 feet thick, with a lack of knowledge regarding how much deeper they extend. The outcropping is along a hillside, in most places so heavily covered with soil that the exact thickness of the deposit could not be determined without a greater expenditure of labor than it was possible to make while the field investigations were in progress. It is certain, however, that there is a large amount of gypsum in this part of the state. Different well drillers were interviewed, all of whom reported that in almost every well for some miles around gypsum was found with a thickness varying from 2 to 5 or 6 feet.

From the indications above given regarding the existence of gypsum throughout the state in the territory between Blue Rapids and Geuda Springs, it is probable that the Permian shales carry vast quantities of it which have not yet been dis-

covered. Owing to its solubility as erosion wears away the surface in most cases the gypsum would dissolve a little more rapidly than erosion would remove the covering, so that it would be found beneath the surface covering of soil and other refuse matter produced by erosion.

Medicine Lodge Deposits.

The gypsum of the Medicine Lodge area is entirely rock gypsum, is white in color, and in the lower portion of the stratum it is very compact. This portion is used at the Medicine Lodge mill for the manufacture of *terra alba*. The upper portion has more of the sugary texture, and is used in the manufacture of wall plaster. The satin spar which is found throughout the Red Beds below the gypsum is in the form of wavy plates, with perpendicular needles, and variable in character. Some of it is soft, and readily crumbles, while other portions are compact and glassy in appearnce.

EXTENT OF THE AREA.

This southern gypsum area is the largest in Kansas, and, with its continuation in Oklahoma and Texas, forms the largest gypsum area in the United States. The rock extends from near the town of Medicine Lodge westward through Barber and into Comanche county, southward into Oklahoma and Texas, and passes under the Tertiary gravels to the north. The trend of the outcroppings of the deposit is the characteristic one of the state, northeast to southwest.

The gypsum is first seen six miles southwest of Medicine Lodge, in an isolated range of hills three miles long and separated by a narrow valley from a second hill one mile in length. The valleys of East and West Cedar creeks, two miles wide, separate these hills from the next series, in which the gypsum plateau is continuous to the west. Medicine Lodge river cuts the gypsum in a valley six or seven miles wide. The northern limit of the gypsum cannot be determined, for it is covered with Tertiary deposits. Salt Fork and Sandy creeks cut out broad valleys to the south, and the streams in the eastern portion of Comanche county have removed much of the stratum;

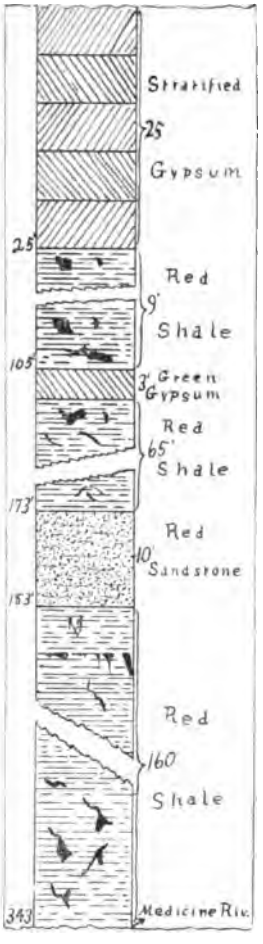


FIG. 5. Geologic Section of Medicine Lodge Hills, Seven Miles Southwest of Medicine Lodge.

but the gypsum is continuous over the greater portion of western Barber and eastern Comanche counties. The rock usually lies near the 1800-foot contour line, as shown in Plate IV.

In the eastern part of Comanche county, on Cave creek, a second gypsum layer 15 feet thick is found, 15 feet above the Medicine Lodge layer. This upper layer was called the "Shimer gypsum" by Cragin.[34] It appears to be a local deposit.

GEOLOGICAL RELATIONS.

Looking west from the town of Medicine Lodge one can see in the distance a range of hills of erosion with sloping sides and level tops. These hills extend in a north and south direction and are called the Gypsum Hills. The sides are composed of the red clays and shales of the Red Beds, the age of which is still somewhat uncertain, but they probably belong to the Permian. The cap rock is a ledge of solid gypsum, which has protected to a considerable extent the underlying soft strata.

The base of the hills, Plate VII, is a massive red sandstone. A second red sandstone is found 125 feet higher, and 100 feet above this comes the ledge of gypsum forming the top of the hills. This gypsum layer varies from 3 to 20 feet in thickness,

34. Loc. cit.

depending upon the amount of erosion. Forty feet below the gypsum is a green gypseous sandstone 2½ feet thick, which stands out as a prominent ledge through the hills. The red clays and shales below the gypsum contain an interlacing network of selenite and satin-spar layers of variable thickness. This material has been dissolved out of the solid stratum and carried downward through the agency of circulating water and redeposited.

At the town of Medicine Lodge is located the gypsum mill shown in Plate XXV, operated by Best Brothers, and built in 1889. The lower story of the mill is constructed of stone, but the upper is a frame structure. At the side of the mill is a Krantz patent kiln, 8 feet in diameter and 17 feet high, in which the rock is calcined again, forming a very hard and durable cement known as Keene's (or Robinson's) cement.

Another gypsum mill was built near Sun City, but it has not been in operation for a year or more.

SOLUTION EFFECTS.

In the western part of Barber and the eastern part of Comanche counties the solvent effects of water on the gypsum are well shown, for here are found natural bridges and underground water courses. On Cave creek, four miles west of Evansville, is the Big Gypsum cave in the Medicine Lodge gypsum. A stream of considerable size flows into the west entrance and out of the east one, making the cave, in reality, an underground water course. The length of the cave is at least 100 feet, with a roof at the east entrance 15 feet above the water level, but which soon narrows down to a height of 3 feet. The floor is strewn with large slabs of white gypsum. At the center is an opening through the roof to the sky above. This hole is a few feet in diameter in the cave and 30 feet on the surface and is nearly circular. The western half of the cave is low and the floor is muddy and covered with water so as to be almost impassable. The section near this cave shows 30 feet of the Medicine Lodge gypsum separated by 15 feet of red shale from the Shimer gypsum, which is 15 feet in thickness. This is the typical exposure of the Cave Creek formation of Cragin.

The natural bridges found here represent remnants of old caves or underground water channels whose roofs have partly fallen in. One of the best of these natural bridges is found on Bear creek, south of Sun City, as shown in Plates XXVI and XXVII. It is thus described by Professor Cragin in the paper to which reference has already been made:

"This bridge spans the cañon of the creek, here about fifty-five feet from wall to wall. The height of the bridge above the bed of the creek is at the highest point forty-seven feet, at lowest thirty-one, and at middle thirty-eight. The width of the bridge at the middle is thirty-five feet. The upper surface of the bridge declines toward the down-stream side, but not so much that a wagon drawn by a steady team could not be driven across it. The thickness of the arch is therefore greater on the up-stream side, where it measures twenty-six feet, than on the down stream. The relief of the vicinity seems to indicate that at a geologically recent time Bear creek here flowed to the east of its present course, and that its waters, becoming partially diverted by an incipient cave, enlarged the latter, and finally were wholly stolen by it, the cave at length collapsing, save at the portion now constituting the natural bridge."

Other Lesser Deposits.

GYPSUM IN THE COAL MEASURE SHALES OF SOUTHEAST KANSAS.

In numerous places in the Coal Measure shales of southeastern Kansas, gypsum crystals are found in comparative abundance, but not in sufficient quantity to be of any considerable economic importance. They are usually in the soil and clay near the surface. The size of the crystals vary from those of microscopic dimension to almost an inch in diameter, with the majority of them ranging from one-eighth to three-eighths of an inch. Sometimes in a corn field one has to dig less than six inches to find them. Elsewhere the last washing of a heavy rain exposes them along the bank of a little stream.

They probably have originated principally through the action of soluble iron sulphate on calcium carbonate, the iron sulphate having been produced by the decomposition of pyrite. The shales in the vicinity of a gypsum deposit are usually quite heavily charged with pyrite. As weathering decomposes the shales the pyrite changes to iron sulphate, and is carried here and there until it comes in contact with the limestone abundant in such localities. One of the noticeable features of such locali-

ties is the large amount of iron sulphate present in the well water whenever the wells have penetrated into the undecomposed shales.

The presence of such gypsum is interesting principally from theoretical considerations, illustrating, as it does in a beautiful manner, one of the possible modes by which gypsum may be formed.

GYPSUM IN THE CRETACEOUS SHALES.

In many parts of the state, where the different Cretaceous shale beds are exposed to the surface, fine crystals of gypsum are frequently found. Along the Smoky Hill river, in Ellsworth and McPherson counties, such crystals are particularly numerous. Some of them measure from three to four inches in length, and are magnificent museum specimens of well formed crystallized gypsum. They do not occur in sufficient abundance to be of any importance for manufacturing purposes.

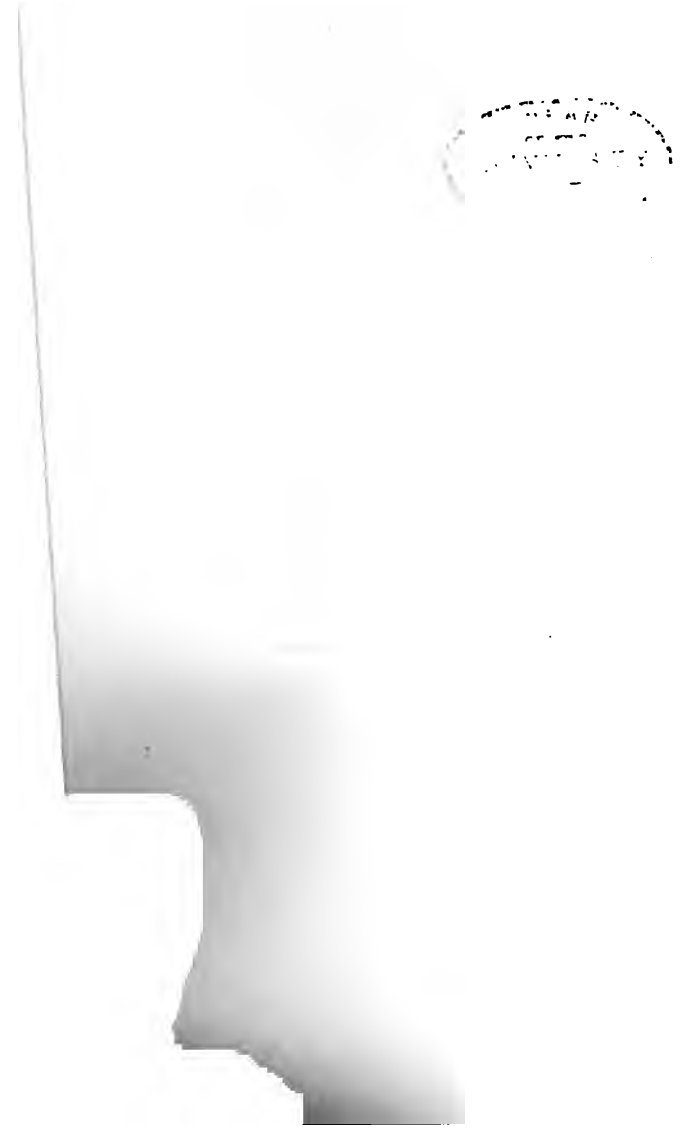
The origin of such gypsum is not readily apparent. It may be similar to that above described for the Coal Measure shales, but the evidence in favor of it is not so strongly marked here. Another possible explanation of it is the leaching out of the small quantities of gypsum originally included in these shales and the concentration of the same at or near the surface where such waters evaporate. A third, but less probable, origin is that of a crystallization of gypsum crystals from the ocean water in which the shales were formed. At any rate, some of the finest museum specimens of crystallized gypsum known to the writer have been found in these localities.

GYPSUM IN THE TERTIARY FORMATIONS.

In the southwestern part of the state where the Tertiary formations come immediately in contact with the Red Beds, the lowermost portions of the Tertiary sands are frequently filled with well formed gypsum crystals. This is particularly true in the southwestern part of Meade county and in different places in Seward county. Here for a distance of from 50 to 100 feet above the contact line between the Red Beds and the Tertiary, gypsum crystals are abundant, formed as perfectly as any known

GYPSUM ROCK, SPOTTED WITH DARK SELENITE CRYSTALS. FROM CROWN PLASTER COMPANY'S MINE, NEAR SOLOMON.

Photographed by Grimsley, 1898.



GYPSUM CAVE SEVEN MILES SOUTHWEST OF HOPE, DICKINSON COUNTY.

Photographed by Haworth, 1897.

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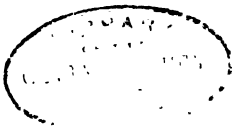
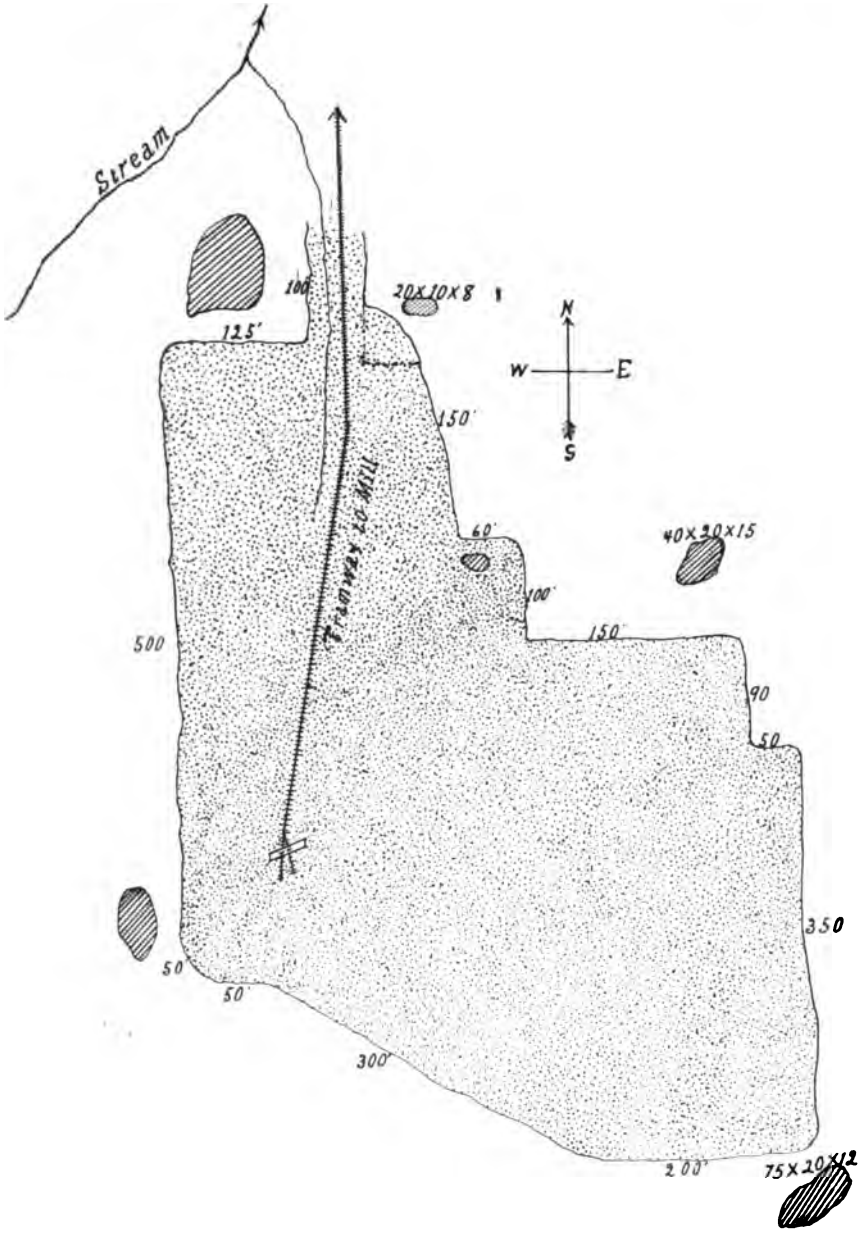
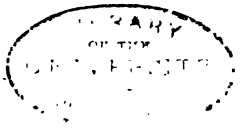
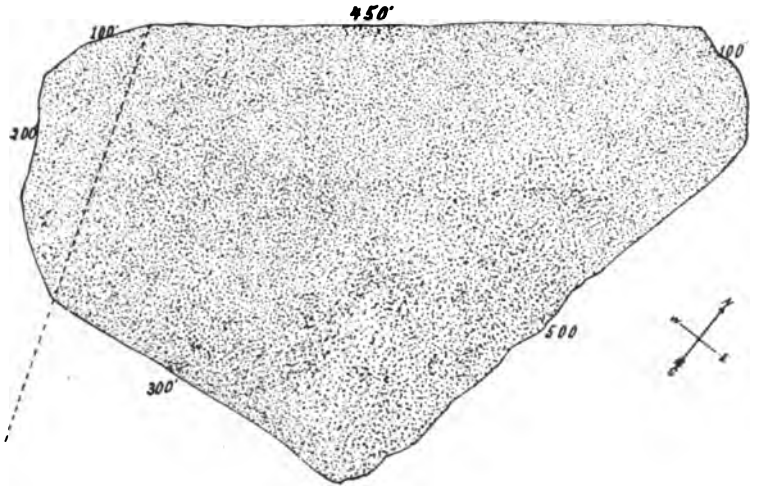


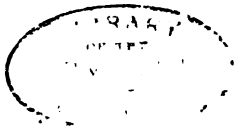


MAP (IN PART) OF AGATITE GYPSUM EARTH DEPOSIT SOUTH OF DILLON, SHOWING ACTUAL WORKING.



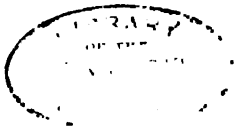


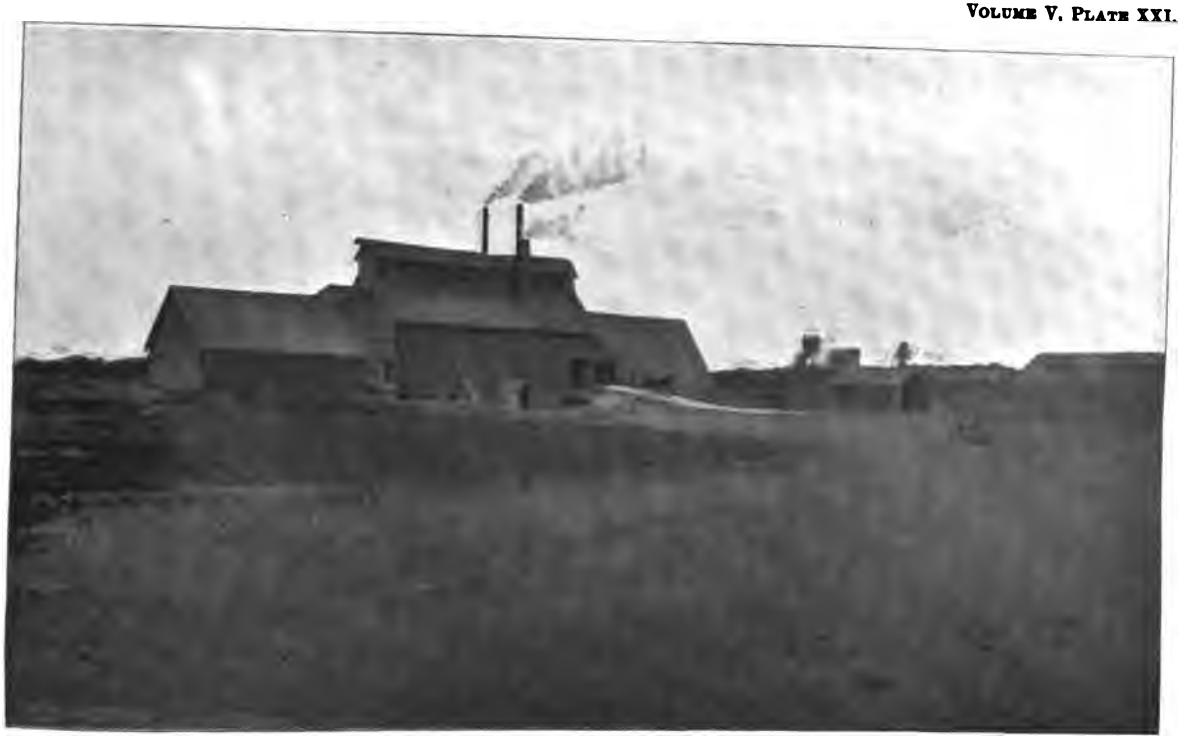
MAP (IN PART) OF THE ALUMINITE GYPSUM EARTH DEPOSIT SOUTH OF DILLON, SHOWING ACTUAL WORKING.



GYPSUM EARTH DEPOSIT AND MILL OF ACME CEMENT PLASTER COMPANY, RHODES, MARION COUNTY.

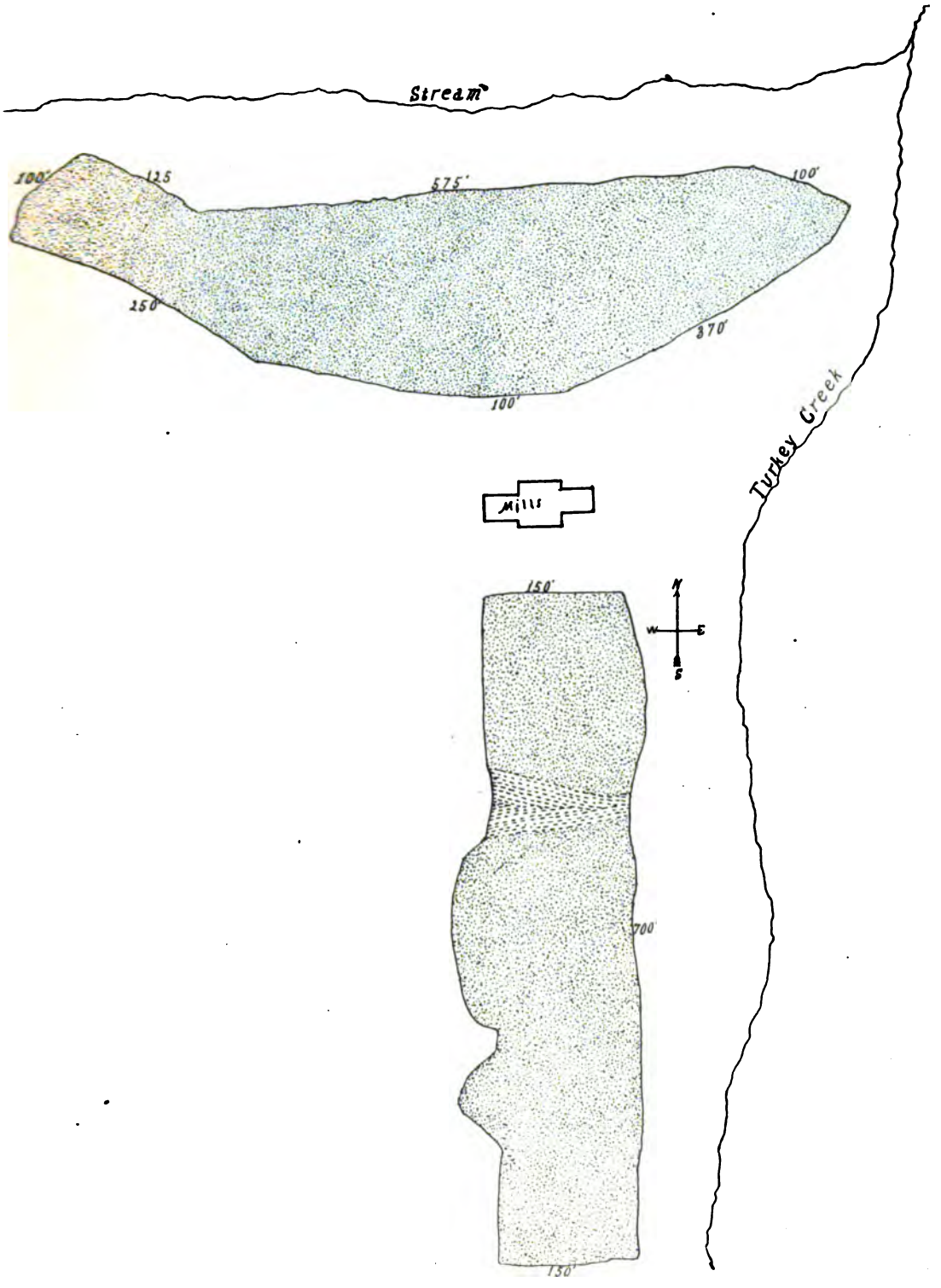
Photographed by Grimsley, 1897.





GYPSUM EARTH DEPOSIT AND MILL OF ACME CEMENT PLASTER COMPANY, RHODES, MARION COUNTY.

Photographed by Grimsley, 1897.



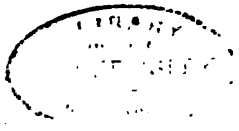
MAP (IN PART) OF THE ACME GYPSUM EARTH DEPOSIT NEAR RHODES, SHOWING ACTUAL WORKING.

AGATITE CEMENT PLASTER MILL AT LONGFORD, CLAY COUNTY.

Photographed by Grimsley, 1897.

GYPSUM EARTH DEPOSIT, LONGFORD, CLAY COUNTY.

Photographed by Grimsley, 1897.



THE BEST BROTHERS' KEENE'S CEMENT PLASTER MILL, MEDICINE LODGE.

Photographed by Grimsley, 1897.

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elsewhere in the state. Likewise the same Tertiary beds at different places have considerable saline properties, something which is entirely unknown to them elsewhere in the state.

It is probable, as Haworth has already pointed out, that this gypsum has originated through an upward movement of the water through the Red Beds beneath, which served as a source of the gypsum, and that the crystallization was produced by surface evaporation at or near the present localities of the gypsum.

Here also the amount of the gypsum is not sufficiently great to make the deposits have any considerable economic importance.

CHAPTER V.

ORIGIN OF GYPSUM.

General Theories of Origin.

In order to explain the conditions given and to account for the origin of the gypsum deposits of Kansas, it will be well first to outline the different theories advanced on this subject.

DEPOSITION FROM SEA WATER.

Gypsum has been deposited by the evaporation of sea water in enclosed lakes or bays which have been cut off from the ocean. Sea water, according to the analyses in the Challenger Reports, contains 3½ per cent. of mineral matter. When this is analyzed the following salts are found:

Chloride of sodium (common salt)	77.758
Chloride of magnesium	10.878
Sulphate of magnesia	4.737
Sulphate of lime (gypsum)	3.600
Sulphate of potassium	2.465
Carbonate of lime	0.345
Bromide of magnesium	0.217
Total	100.

When such a body of water is cut off and evaporated, the gypsum is deposited after thirty-seven per cent. of water is removed, and common salt only after the removal of ninety-three per cent. The normal order would be a deposit of gypsum and then a much heavier deposit of salt. But as ninety-three per cent. of the water must be evaporated before the salt would be thrown down, the evaporation might go far enough for the deposition of gypsum, but not far enough for salt; or the salt might be deposited, and subsequently removed by solution.

Gypsum deposits are more wide-spread in nature than salt, but usually occur in thinner beds.

This is the most generally accepted theory for the origin of gypsum, and probably applies to most of our larger gypsum deposits.

DEPOSITION BY THERMAL SPRINGS.

Gypsum is deposited by some thermal springs, as in Iceland, where it is formed by decomposition of volcanic tufa by acids dissolved in the water. The sulphurous acids become oxidized to sulphuric, and then convert the carbonates, especially of lime and magnesia, into sulphates. Through evaporation the sulphate of lime is deposited, forming layers of fibrous and selenitic gypsum.

DEPOSITION THROUGH VOLCANIC AGENCIES.

Dawson,[35] following Lyell, explained the origin of the gypsum in Nova Scotia, as follows: First, there was an accumulation of numerous thin layers of limestone, either so rapidly or at so great depth that organic remains were not included in any but the upper layers. Second, there was an introduction of sulphuric acid, in solution or in vapor, which was a product of volcanic action. Then for a long time the acid waters acted upon the calcareous material without any interruption from mechanical detritus. The limestone and calcareous matter are changed to the sulphate, and gypsum of good quality accumulates in considerable thickness.

HUNT'S CHEMICAL THEORY OF GYPSUM FORMATION.

Hunt's[36] chemical theory of the formation of gypsum is somewhat complex, but he believed it applied to a large part of the gypsum deposits of marine and fresh-water origin. In his own words the theory is as follows:

"1. The action of solutions of bicarbonate of soda upon sea water separates, in the first place, the whole of the lime in the form of carbonate, and then gives rise to a solution of bicarbonate of magnesia, which, by evaporation, deposits hydrous magnesian carbonate.

"2. The addition of solutions of bicarbonate of lime to sulphate of soda or sulphate of magnesia gives rise to bicarbonates of these bases, together with sul-

35. "Origin of Gypsum Plaister Cove, Nova Scotia," Quar. Jour. Geol. Soc., vol. 5, p. 339, 1849.
36. Quar. Jour. Geol. Soc., vol. 16, p. 154, 1859; Chem. and Geol. Essays, pp. 80-92, 1878.

phate of lime, which latter may be thrown down by alcohol. By the evaporation of a solution containing bicarbonate of magnesia and sulphate of lime, either with or without sea salt, gypsum and hydrous carbonate of magnesia are successively deposited.

"3. When the hydrous carbonate of magnesia is heated alone, under pressure, it is converted into magnesite; but if carbonate of lime be present, a double salt is formed, which is dolomite.

"4. Solutions of bicarbonate of magnesia decompose chloride of calcium, and, when deprived of their excess of carbonic acid by evaporation, even solutions of gypsum, with separation of carbonate of lime.

"5. Dolomites, magnesites, and magnesian marls have had their origin in sediments of magnesian carbonate formed by the evaporation of solutions of bicarbonate of magnesia. These solutions have been produced either by the action of bicarbonate of lime upon solutions of sulphate of magnesia, in which case gypsum is a subsidiary product, or by the decomposition of solutions of sulphate or chloride of magnesium by the waters of rivers or springs containing bicarbonate of soda. The subsequent action of heat upon such magnesian sediments, either alone or mingled with carbonate of lime, has changed them into magnesite or dolomite."

DEPOSITION THROUGH ACTION OF PYRITES UPON CARBONATE OF LIME.

Pyrites or iron sulphide decomposing in clays may change the carbonate of lime into sulphate of lime, and so form gypsum, usually in rather small amounts and scattered through the clay.

Kansas in Permian Time.

At the opening of Permian time all the eastern portion of Kansas was part of the interior land mass, while the middle and western areas were under the waters of the western sea. During the Permian the middle area gradually emerged, commencing first at the north and extending southward. During the Neosho division, the northern area was joined to the eastward land, and the sea was driven back south and west.

In the Marion epoch, the central portion emerged from beneath the sea, for the Dakota sandstone of the Cretaceous rests unconformably upon it, showing that it must have been dry land, and then depressed again in Cretaceous time. The southern area was under the sea at the close of the Permian, when the Red Beds were laid down. At the end of this period it was raised into land, for the Cretaceous and Tertiary rest unconformably upon the Red Beds. These movements crowded the sea back to the west, and added to the land area of this state.

The western part remained a sea until the close of the Cretaceous period.

The evidence of alternating shales, limestones, and gypsum layers shows that the conditions were undergoing changes through much of Permian time. The land was undoubtedly oscillating up and down. There were probably marked climatic and other physical variations. The Permian was a period of unrest. Part of the time the waters were clear, with conditions favorable for marine life, and the limestones were formed. At other times the waters were muddy through quantities of sediment carried in, and shales were deposited. These shales were sometimes sandy and light colored in the central and northern parts of the area, but more argillaceous and red toward the south. The conditions at the south were unfavorable for life, as no animal fossils are found throughout the Red Beds series.

The swamp conditions of the Carboniferous had almost disappeared, for no coal seams are found. In the earlier part of the period, the marine life did not differ much from the later portion of the Carboniferous, and the fossils are quite similar. There is no evidence of any great disturbance through the period, so the changes must have taken place very slowly. The land movements probably formed bays, which were sometimes temporarily and sometimes permanently cut off from the main ocean.

Origin of the Kansas Gypsum.

There is no evidence of volcanic activity in the Kansas Permian, Cretaceous or Tertiary rocks, and volcanic rocks of any extent are absent; so Dawson's theory of sulphurous vapors acting on limestones, or the action of acids from decomposed volcanic tufa, cannot be applied to these deposits. Magnesian rocks are not found near the gypsum strata, and there is no evidence at hand to even suggest Hunt's chemical theory. The deposits are too extensive and of too great thickness to be explained by the action of iron pyrites on carbonate of lime.

The only theory which seems to accord with all the facts is

the first one outlined: that is, due to evaporation of sea water in lakes or bays.

Through some disturbance an arm of the sea was cut off, at least for a time, and the water evaporating deposited gypsum. At the north the gypsum rock is underlaid by limestone. This limestone is an evidence of marine life; but no traces of life are found above within the gypsum strata. Life for the most part would be destroyed in a basin where the water was concentrated enough to deposit gypsum. There is thus in this area evidence of abrupt change in physical conditions. The gypsum contains clay seams irregularly distributed through the beds, showing that the basin received the drainage of small streams carrying their loads of fine sediment. These conditions remained until at least 8 or 9 feet of gypsum were deposited, and then the old connection with the sea was restored by slow depression of the area. The gypsum formation ceased and sediment was deposited over it in the series of sandy shales now found throughout the area. It is not possible to say whether the evaporation continued long enough for the deposition of salt, but probably it did not, as there is no trace of salt detected near the gypsum in this entire region.

The northern land was then elevated and joined to the eastward land and conditions then became favorable for gypsum formation in the Marion epoch in the central part of the state. In a similar bay the gypsum was deposited almost free from clay seams, but intercalated with shale beds affording good evidence of alternating conditions favorable for gypsum formation and sedimentation.

The gypsum rock is thicker in the southern part of the area, and salt deposition is indicated by presence of salt springs and wells, but it has now been dissolved from over the gypsum, where it was probably comparatively thin. The great salt beds just to the southwest in the direction of dip of the rocks may have been deposited later in the stage of gulf evaporation, after the waters had deposited their gypsum where we now find it and had retreated further to southward.

In the southern part of the state, after the central area had been raised into land, shallow water conditions prevailed. Thick deposits of shales were laid down, interrupted for a time while the massive gypsum was deposited. The gypsum has no clay seams in it, and is compact and pure. This interruption appears strange and difficult to explain. It may have been due to some climatic change whereby the rainfall was lessened, and so the erosion and amount of sediment carried into the gulf would be checked. Again, there may have been land movements lowering the surrounding land, and the erosion and transportation of sediment thereby stopped.

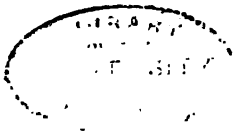
In the western part of Barber county there were two gypsum deposits, separated by shales. The conditions after the formation of the Medicine Lodge gypsum were apparently similar to those before, and red shales were again deposited. The appearance of the shales above and below the gypsum to-day is different. The shales below are bound together by the selenitic network which has been formed by solution of the gypsum layer above and a deposition below. This action is without doubt going on to-day. In the shales above the gypsum this feature is absent.

Origin of the Secondary Gypsum Deposits.

The deposits of earthy gypsum in the central part of the state were formed at a much later time than the rock deposits we have been describing. They occur in low swampy ground and strong springs of gypsum water occur in nearly all of them.

At the same level or 10 to 20 feet below the earth is a stratum of solid gypsum, while near most of these deposits no gypsum is found above. Near the bottom of the Rhodes deposit Dr. S. Z. Sharp found recent shells of genera *Planorbis* and *Physa*, and an Indian spear-head was also found. Similar shells were found by the writer, in the Longford earth near the bottom of the deposit. In the earth south of Dillon bones and shells were found.

Gypsum in a form resembling satin spar and in an earthy form is deposited at the present time in dry weather to the extent of a half inch in a few days by the evaporation of running



THE BEST BROTHERS' KEENE'S CEMENT PLASTER MILL, MEDICINE LODGE.

Photographed by Grimsley, 1897.

NATURAL BRIDGE IN MEDICINE LODGE GYPSUM, BARBER COUNTY (SOUTH SIDE).
Photographed by Grimsley, 1897.

tances. Some sand, clay, lime carbonate, and organic material are shown by chemical analyses and by the microscope, and these may be due to surface agencies. The water circulating through or near the underlying gypsum rock dissolved a portion of the rock and carried it upward in the springs to the surface of the swamp, where the mineral was precipitated through evaporation aided by the action of organic matter of decaying vegetation.

A crust of gypsum would thus be formed and would increase in thickness until all the underlying rock was removed. Now, in some of these deposits borings detect no gypsum below the deposits, but it is found in wells outside at a level below the earth. In such places probably all the gypsum rock adjacent to the gypsum earth area has been removed by solution. Again by building up the swamp floor to a certain hight the rise of gypsum water springs may have been so checked as to hinder the earth formation. Whatever the cause, the gypsum earth deposit is not now forming over the entire area in any appreciable amount.

The uneven thickness of the deposits, some varying from 3 to 8 feet within the main part of the deposit, shows that the conditions were more favorable at certain points than others. Probably these thicker portions were nearer the outlet of stronger springs.

The deposits were formed in a comparatively short period of time. The presence of modern fresh water shells shows that the deposit is a recent one, formed long after the rock gypsum of the same region.

CHAPTER VI.

TECHNOLOGY OF GYPSUM.

General Properties.

While gypsum rock was known to the ancient investigators and used in those early times as fertilizer, and burned to form the plaster of Paris, its composition and most of its properties were not known or even investigated.

LAVOISIER'S EXPERIMENTS.

The first experiments along this line were made by Lavoisier and published by him in the proceedings of the Académie de Sciences in 1765. He decomposed the gypsum rock by means of carbon, and sulphurous vapors were set free with the formation of a sulphur deposit which showed the presence of sulphuric acid. He then decomposed a solution of gypsum in water by means of potash, and showed the presence of lime.

After finding the elements composing gypsum, Lavoisier tried a synthetic experiment to prove the composition as determined, and he thus describes the result:

"I then took concentrated sulphuric acid of which the weight was about double that of the water, and of known purity; I added more water, and I then added carbonate of lime until there was no more effervescence. I thus obtained a selenite which is a true gypsum."[37]

Thus at a very early day the qualitative composition of gypsum was determined by very careful work by one of the founders of chemical science.

Later quantitative analyses were made of various specimens of gypsum. One of the early analyses was made of the white

37. Academie des Sciences, 1765.

gypsum near Monte Marte, in the neighborhood of Paris. This is the locality which has given the name plaster of Paris to the calcined plaster, which holds all over the world. This analysis gave:

Water	7.10	per cent.
Sulphate of lime	92.56	"
Carbonate of lime	.32	"
Silica	.02	"
	100.	

Other analyses were made and the theoretical percentages of the components of a pure gypsum were computed, which have been slightly revised from time to time; but now these percentages may be given as 46.6 per cent. of sulphuric acid, 32.5 per cent. of lime, and 20.9 per cent. of water. The chemical formula for gypsum would be $CaSO_4+2H_2O$; and when the mineral is deprived of the water it is known as anhydrite.

Physical Properties of Gypsum.

In its physical properties gypsum is one of the softest minerals, and in the old inaccurate Mohs' scale it ranked No. 2 in the scale of 10, with a specific gravity when pure of 2.32. Gypsum crystallizes in the monoclinic system of the mineralogists in the form of plates or prisms with pyramidal terminations. The relative lengths of the crystal axes, or the length of the inclined axis, which passes from front to back of the crystal, to the axis which passes from right to left, to the vertical axis, is represented by the formula $0.6891 : 1 : 0.4156$, with the angle of the inclined axis to the vertical, 81° 5′. Twin or united crystals, as shown in Figure 8, are very common, where the crystals are twinned on the ortho-pinacoidal face, which is the face at right angles to the vertical, and to the right and left axes.

The typical forms of the crystals are shown in Figures 6 and 7. The cleavage is almost perfect on the face *b*, which explains the plate-like character of gypsum found in the rocks. Cleavage very often takes place on the face *n*, cutting across the first cleavage. The faces of the twin crystals are sometimes rounded, as shown in Figure 9. This is especially characteristic of many

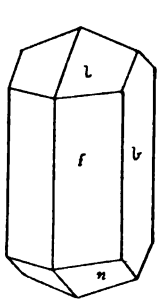


FIG. 6.

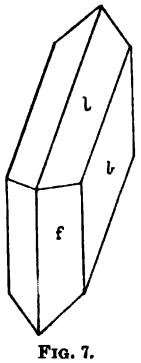


FIG. 7.

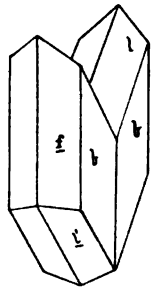


FIG. 8.

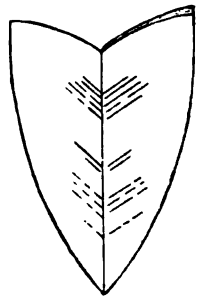


FIG. 9.

Figure 6. Form of gypsum crystal.
Figure 7. Common form of gypsum crystal.
Figure 8. Twinned gypsum crystal.
Figure 9. Twinned gypsum crystal, with edges rounded—Monte Marte twin.

of the crystals near Monte Marte, near Paris, and so these crystals are sometimes called the Monte Marte twins.

Gypsum is only slightly soluble in water, as shown in the following table of Marignac:

Solubility of Gypsum, by Marignac.[38]

Temperature.	One part gypsum dissolves in—	One part anhydrous sulphate lime dissolves in—
At 32° F.=0° C	415 parts of water	525 parts of water.
At 64.5° F.=18° C	386 " "	488 " "
At 75.2° F.=24° C	378 " "	479 " "
At 89.6° F.=32° C	371 " "	470 " "
At 100.4° F.=38° C	368 " "	466 " "
At 105.8° F.=41° C	370 " "	468 " "
At 127.4° F.=53° C	375 " "	474 " "
At 161.6° F.=72° C	391 " "	495 " "
At 186.8° F.=86° C	417 " "	528 " "
At 212° F.=100° C	452 " "	572 " "

The maximum solubility is found at 38° C. or 100° F., and then only one part of gypsum dissolves in 368 parts of water, while about 40 parts of common salt will dissolve in 100 parts of water at a temperature of 60° F.

38. Annales de Chimie, Paris, 5th series, vol. 1, pp. 274 to 281, quoted by Chatard, Seventh Annual U. S. Geol. Survey, and verified by the writer.

PAYEN'S EXPERIMENTS.

Lavoisier, in his memoir quoted above, states that on heating gypsum the water was removed at two different stages, and that three-fourths of it was much more easily removed than the remainder. Payen, in 1830, confirmed this result, and found that gypsum commenced to lose water at a temperature of 115°C., and that the loss rapidly increased up to 204°C. Payen regarded a temperature of 110° to 120°C. to be the best in the manufacture of plaster, but he found by a series of experiments that plaster could be made at a lower temperature if burned long enough. The lowest temperature found was 80°C., and then a long time was required.

Payen's[39] results are included in the following summary:

1. The set of plaster is due to a crystallization of hydrous sulphate of lime.

2. The temperature the lowest at which plaster can be made is 80°C., and the process of manufacture is very easy.

3. A temperature of 110° to 120°C. is sufficient to deprive plaster of all its water and to cook completely.

4. Plaster in small particles favors the drying.

5. Calcium sulphate heated to about 250°C. is dehydrated; at 300° to 400° it loses completely the properties of hydration, or the power of gaining again the water of crystallization, and resembles then hydrated sulphate of lime found in nature. If heated higher, it may result in melting the sulphate of lime.

6. The hardening of plaster by alum is perhaps due to the formation of a double sulphate of potash and lime.

CHATELIER'S EXPERIMENTS.

Chatelier in 1887 conducted some very elaborate experiments on the effects of temperature on gypsum. He powdered the gypsum rock and placed it in a paraffin bath, and connected a thermometer in the bath with a chronograph. On applying heat up to 200° C., or 392° F., there was a constant rise in temperature, with two exceptions. The first halt occurred at 128° C., or 262° F., and the second at 163° C., or 325° F. The first one

39. Chimie Industrielle, 1830, quoted by Landrin, Annales de Chimie, 1874.

was the more pronounced, and Chatelier regarded these interruptions as due to an absorption of heat which accompanied the elimination of water. This would indicate the existence of two different hydrates, whose decomposition took place at the temperatures indicated by the halts on the chronograph. Further, the dehydration was found to be incomplete at 155° C., or 311° F., and complete at 194° C., or 381° F.

In order to prove the composition of the first hydrate, Chatelier heated a saturated solution of gypsum in a closed tube to a temperature between the two halts indicated, or between 130° C. (266° F.) and 150° C. (302° F.), and very delicate, long, rectangular prisms were formed, which were thrown into alcohol, and then analyzed, with the following result:

Water	6.7 per cent.
Sulphate of lime	93.3 " "
	100.

This agrees very closely with the formula $(CaSO_4)_2$, H_2O, where there would be

Water	6.2 per cent.
Sulphate of lime	93.8 " "
	100.

In this compound it is seen that two parts of lime sulphate are united with one part of water, while in the original gypsum one part of lime sulphate was united with two parts of water. Chatelier also found that the incrustation in the boilers of ocean steamers, where salt water was used and where the temperature averages about 165° C. (320° F.), possessed nearly the same composition as the hydrate given above. His analysis was as follows:

Lime carbonate	0.3 per cent.
Iron oxide	2.0 " "
Water	5.8 " "
Lime sulphate	91.9 " "
	100.

Further experiments by Chatelier showed that if ten grammes of powdered gypsum were heated for some time at 155° C., or 311° F., intermediate between the temperatures necessary for the decomposition of the two hydrates, the loss in weight was

uniformly 1.56 grammes which corresponds with one and one-half equivalents of water so that the compound should contain about 6.2 per cent. of water as shown by the formula given. Ordinary plaster of Paris usually contains about seven per cent. of water, so it is a definite hydrate with the formula $(CaSO_4)_2$, H_2O.

The second halt, as has been given, took place at 163° C., or 325° F. From this temperature to 221° C., or 430° F., no change was noted in the plaster; but beyond this temperature, the plaster when mixed with water did not absorb it readily and only set after a long time. If the heat reaches 343° C., or 650° F., the plaster acts like an anhydrite, and it is said to be *dead burned* and will not set on addition of water. If the gypsum is heated further, the substance melts, forming a crystalline mass on cooling which cannot be decomposed by heat except in the presence of organic matter, when it changes into CaS. If this substance is acted upon by carbon dioxide gas (CO_2) and water, sulphuretted hydrogen gas will be formed.

The temperature of burning is thus seen to be all important, and calls for skill and experience on the part of the calciner. If overburned, the plaster sets very slowly. If underburned, the new hydrate is not formed, and the plaster will not set.

The reason why the commercial plasters vary in quality undoubtedly depends to a very great extent on this care of calcining and the companies are very careful to select the best men they can find to watch the kettles which are used in the plaster manufacture. Some of the calciners in the Kansas field have spent many years in learning their trade, and the skill they employ in determining the right point to draw the plaster is remarkable and wonderful to one who watches them. The principles outlined above, though perhaps wholly unknown to them from a chemical standpoint, are familiar from a practical point of view. They all have their secret tests and clues which are jealously guarded.

Set of Plaster.

LAVOISIER'S THEORY.

Lavoisier in those early experiments (1765) on gypsum, quoted before, considered the problem of the setting of plaster of Paris when water was added to it. His early explanation, which has been verified many times since, and which is without doubt the true explanation of the set of plaster, is seldom mentioned in our reports on gypsum; and it is not very generally known by those who are in direct contact with the plaster industry.

As this explanation of Lavoisier is the first recorded discovery of the principle of set in plaster, it will be interesting to quote the original account:

"I took the calcined plaster, as has been described before, and which hardens readily with water. I threw it into a considerable amount of water, in a pan or in a large dish. Each molecule of plaster, in passing through the liquor, seized its molecule of water of crystallization, and fell to the bottom of the dish in the form of small brilliant needles, visible only with a strong lens. These needles, dried in the free air or with aid of a very moderate heat, are very soft and silky to the touch. If placed on the stage of a microscope, it is perceived that what was taken under the lens for needles are also parallelopipeds, very fine, so they are described as thicker, or many thinner, and many more elongated. The plaster in this state is not capable of uniting with water, but if it is calcined anew, these small crystals lose their transparency and their water of crystallization, and become again a true plaster, as perfect as before. One may in this fashion successfully calcine and recrystallize the plaster, even to infinity, and consequently give to it at will the property of seizing water." [40]

This explanation of the formation of fine crystals during the process of set in plaster was generally accepted, and it was given by Payen in 1830 as his first principle.[41]

LANDRIN'S THEORY.

Landrin, in the paper quoted above, which was written in 1874, gives the results of an elaborate study on plaster which

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40. Quoted by Landrin, Annales der Chimie, 1874, pp. 431, 435.

41. See page 87

SELENITE CRYSTALS FROM MASSIVE ROCK GYPSUM SHOWN IN FRONTISPIECE. NATURAL SIZE.

remains to-day a valuable and suggestive memoir. The set of plaster was divided by him into four periods:

"1. The calcined plaster, on contact with water, unites with this liquid and takes a crystalline form.

"2. The plaster dissolves partially in the water, which becomes saturated with this salt.

"3. A part of the liquid evaporates, due to the heat set free in the chemical combination. A crystal is formed and determines the crystallization of the entire mass; a phenomenon which is analogous to that which takes place when a piece of sulphate of soda is placed in a saturated solution of this salt.

"4. The maximum hardness is reached when the plaster loses enough water to correspond exactly to the formula SO_3CaO, $2H_2O$; this maximum being to the remainder in proportion to the quantity of water added to the plaster to transform it into mortar."

In order to test the third and fourth principles, Landrin tried the following experiment. He mixed 23.358 grammes of plaster with ten grammes of water, and the weights found at different intervals were:

In 10 minutes	33.100	grammes,	or loss of	water,	0.258	grammes.
In one hour and 10 minutes	32.623	"	"	"	0.735	"
In 3 days	29.218	"	"	"	4.140	"
In 10 days	27.290	"	"	"	6.068	"
In 18 days	27.283	"	"	"	6.075	"

After this time, no change.

"The plaster lost in calcining 5.715 grammes, equal to the combined water. In 27.283 grammes of plaster, by formula SO_3CaO, $2H_2O$, there would be 5.710 grammes of water, so that drying ceased when plaster reached its original composition."

The maximum hardness then was reached when the plaster contained about 20 per cent. of water. The loss of water was regarded as due to the evaporation, according to Landrin's third principle.

CHATELIER'S THEORY.

Chatelier showed that plaster would set in a vacuum flask, so that evaporation was not a necessary step in the set of plaster, as Landrin maintained in his third principle above.

According to Le Chatelier, the plaster of Paris compound $(CaSO_4)_2$, H_2O dissolves in part in the added water, which diminishes the solubility, and the solution becomes therefore

supersaturated and $CaSO_4$, $2H_2O$, or gypsum, crystallizes out. In other words, the plaster of Paris dissolves, and becomes hydrated, then crystallizes out as gypsum; and every particle of the plaster goes through these steps.

ORIGINAL THEORY.

The theories given above are the only ones so far found in the literature which attempt to explain the set of plaster. Before finding the above references to the process of set in plaster, the writer made independent investigations to determine the cause of the set in calcined gypsum on the addition of water, with the following results:

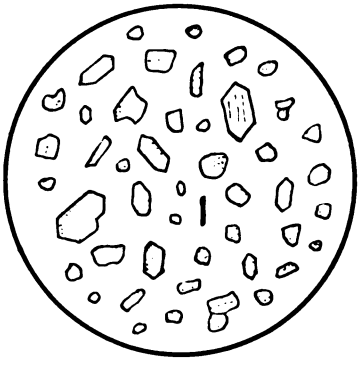


FIG. 10.

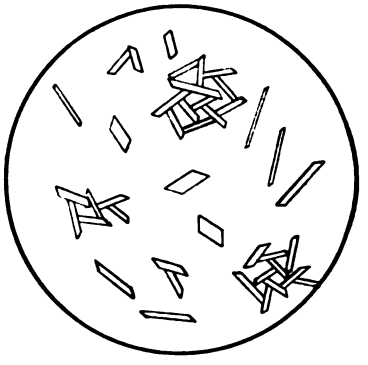


FIG. 11.

Figure 10. Uncalcined gypsum earth from central Kansas, × 500.
Figure 11. Calcined gypsum earth from central Kansas, one-half hour after water was added to it, × 600.

Under the microscope the ground gypsum and the gypsum earth before calcination agree in being composed of rather large masses of varying size, as shown in Figure 10. The former consists of more or less broken crystals, while the gypsum earth shows crystals of more regular shape. After calcination these larger crystals are found to be broken into fine granules of nearly uniform size and shape, as shown in the drawing made from calcined gypsum earth from central Kansas, in Figure 12. As the material is heated, the water is changed into steam through-

out the crystal mass, and, expanding, breaks the crystals into finer particles. There is thus a physical change as well as a chemical one. In the plaster which has not been sufficiently burned the grains are coarser and more irregular.

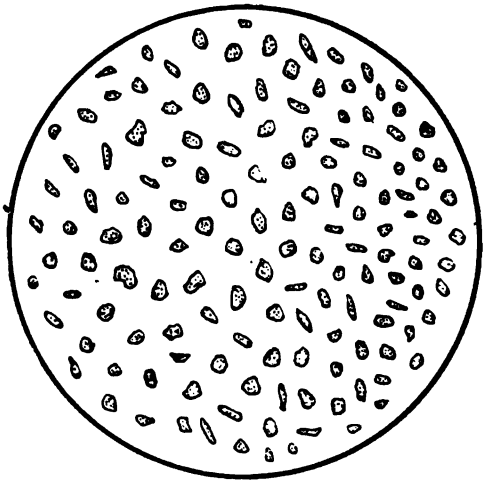


FIG. 12. Calcined gypsum earth from central Kansas, × 500.

Under the microscope, when water is added to the calcined plaster, small needle-like prisms are seen forming and shooting out here and there. As these become more and more abundant, they unite with one another and rapidly form a solid mass, in which the individual crystals can scarcely be distinguished. Open spaces are left in the mass apparently filled with water, and finally these are closed, and a firm solid mass results. The network formed by these crystals at first, is imperfectly shown in the drawing in Figure 11.

The treatment of uncalcined gypsum with water in the same way shows very little change, Figure 13. Gypsum crystallized from solution by evaporation shows crystals which are not needle shaped, but they are broader and show considerable irregularity. They are more or less twinned and they do not interpenetrate, but form a loose mass which readily crumbles. This crystalliza-

FIG. 13.

FIG. 14.

Figure 13. Uncalcined ground gypsum in water, after standing three days. Blue Rapids.
Figure 13. Gypsum crystallized from solution in water, after standing three days. Blue Rapids.

tion is shown in Figure 14, which was obtained by evaporating a solution of uncalcined gypsum on a glass slide and then examining it under a high-power microscope.

Crystallization is aided by the small size of the grains or particles in the plaster, and the finer grained plasters set more rapidly than the coarser ones, as one may observe in the fine dental plasters as compared with ordinary plaster of Paris.

My own experiments agree then with those given by Lavoisier, Payen, Landrin, and Chatelier, in that the set of plaster is due to the formation of a crystalline network. The cause of the formation of this network of crystals, or the factor which starts the crystallization is the troublesome part to explain, and this has attracted less attention among investigators along these lines.

When gypsum is burned it forms, as Landrin showed and as analyses prove, the hydrate $(CaSO_4)_2$, H_2O. Marignac called attention to the fact that if water is added in excess, this hydrate in part is dissolved, forming first a clear liquid which then becomes turbid, and crystals of $CaSO_4$, $2H_2O$, or gypsum, are thrown down. Now an examination of these formulæ shows that three parts of water have been taken up by the hydrate,

$$(CaSO_4)_2,\ H_2O+3H_2O=2(CaSO_4,\ 2H_2O).$$

So first, the plaster partially dissolves in contact with the water, as Landrin pointed out in his second principle, and as accepted by Chatelier. Next, some change takes place whereby, according to Marignac's experiment, the liquid becomes turbid and crystallization begins. Landrin thought evaporation took place as a result of the heat formed by chemical combination, and that a crystal was then formed which started the crystallization through the entire mass. Chatelier showed by experiment that evaporation was not necessary, and he argued that by the taking up of this water the solubility of the hydrate was decreased, and so, on account of the resulting supersaturation, crystallization ensued.

The solution of the hydrate in these experiments is certainly saturated, and all that is needed is something to start the crystallization. From a study of saturated solutions in the laboratory, it is well known that if crystals are introduced into such solutions, crystallization will result and go on until the salt has crystallized out.

The effect of heat on gypsum in the burning of plaster, as we have shown, is to remove a certain percentage of water, and to break up the small masses of the rock into finer and finer particles, microscopic and even ultra-microscopic in size. If the heat is not carried too far certain particles through the mass may still possess their crystalline form as shown in Figure 12, and so they are true crystals though very small. These minute crystals in the saturated solution would start the process of crystallization. Their growth would cause the turbidity of the solution noted by Marignac, and would result in a precipitation of small gypsum crystals, thus forming the crystal network which constitutes the set of plaster.

If the plaster is underburned the gypsum is not reduced to the proper fineness and uniformity, and so would not permit the crystallization to go on in the way it would in the properly burned plaster. But of more importance, the hydrate represented by plaster of Paris would not be formed.

If the plaster is overburned, the plaster will be so completely comminuted that no minute crystals will be left to start the

crystallization. Where the plaster is slightly overburned, the crystals are extremely fine and crystallization goes on very slowly and imperfectly.

This theory of the set of plaster seems to accord with the facts noted and appears simpler and more plausible than the views already advanced. The influence of retarders on the set of plaster will be discussed in connection with that subject.

Process of Manufacture.

In Kansas there are eleven mills engaged in the manufacture of plaster from gypsum, and two equipped mills not now in operation. Six of the eleven use the gypsum rock and five use the gypsum earth. The process of manufacture is practically the same in all the mills of the northern and central areas except the mills using the gypsum earth do not require crushing machinery.

The machinery used in the Kansas mills is manufactured by Butterworth & Lowe, of Grand Rapids, Mich., and also by two Kansas companies: the Ehrsam Machine Company, of Enterterprise, and the Great Western Manufacturing Company, of Leavenworth.

On the ground floor of the mill are placed the crusher and nipper. The crusher, shown in Figure 15, has face plates or jaws of chilled iron which have a backward and forward crushing motion, operated by steam or water power. Blocks averaging fifty pounds weight are thrown into this machine and crushed into pieces about the size of a man's hand. These small masses drop from the crusher into the cracker or nipper, which is set in the floor just under the crusher. This machine, with its interior revolving shaft, works somewhat like a coffee-mill, and further crushes the gypsum into fragments of the size of small gravel, which fall into the buckets of a chain elevator, whereby they are raised to a bin on the second floor. From this bin the gypsum particles pass through a spout into an ordinary buhr mill, where it is ground into flour.

The buhr stones are ground down smooth in course of time by the friction of the gypsum particles, and then they must be

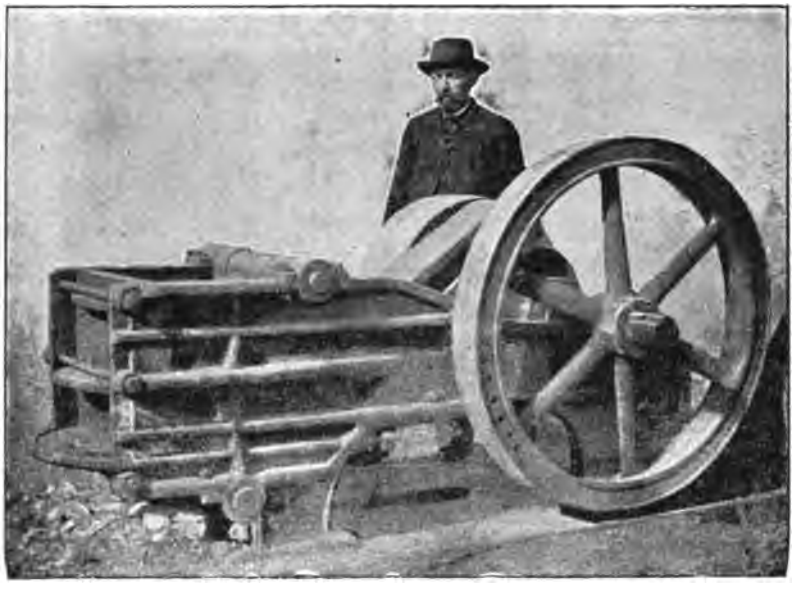


FIG. 15. Gypsum Crusher, made at Enterprise, Kan.

redressed. This operation requires skilled labor, and is a slow and expensive process. It is estimated to cost thirty dollars to dress the buhrs, and the operation takes about ten days. In order to avoid this difficulty other means of crushing have been employed. In some mills the steel flour mill rolls have been used, and it is claimed that these were successful. However, they are not used in many of the rock mills. Another method of grinding has been invented by the Stedman's Foundry and Machine Works, of Aurora, Ind., and is known as a lime disintegrator. This machine, as shown in Figures 16 and 17, consists of two cages with short cross-bars, and these cages travel at high speed in opposite directions. The gypsum is fed into the hopper to the center of the cages. The centrifugal force carries it between the bars of the cages. These bars passing each other in opposite directions beat the rock to powder by impact against the bars, and by the striking of the gypsum particles against each other. There is no danger of choking or clogging the machine, and the action is rapid. This means of grinding

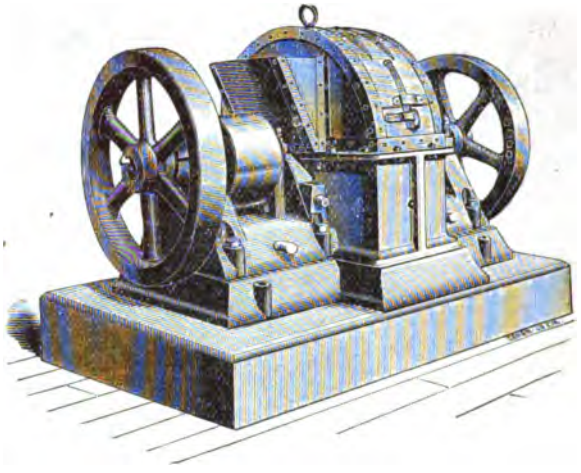


FIG. 16. Gypsum Disintegrator, made at Aurora, Indiana (closed).

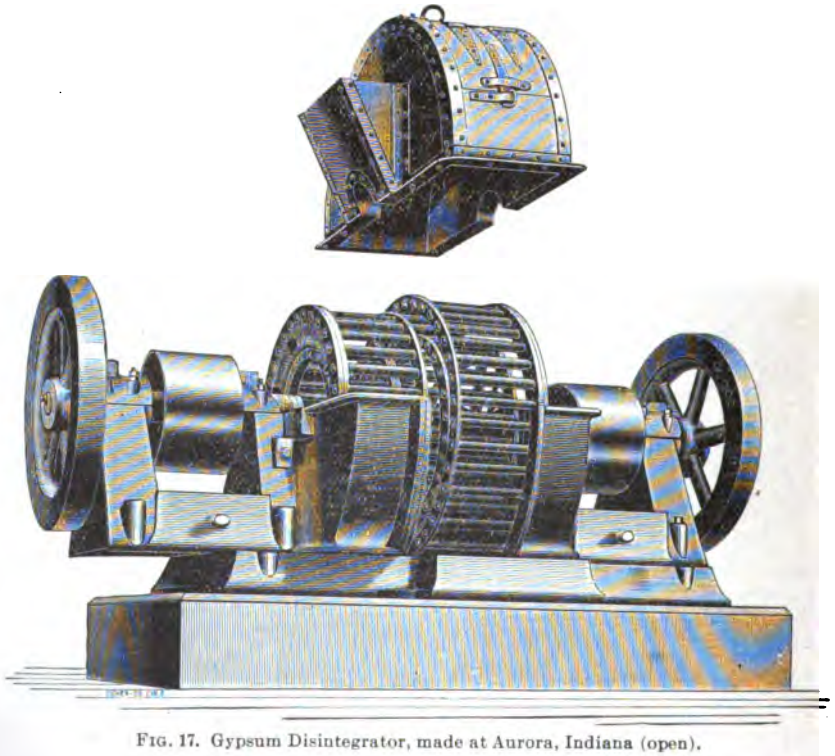


FIG. 17. Gypsum Disintegrator, made at Aurora, Indiana (open).

FIG. 18. Gypsum Bucket Elevator.

is used at the Chicago mill of the Western Plaster Works and in a number of the mills in Michigan. The capacity of a fifty-inch disintegrator is sixty to seventy-five tons in ten hours.

After the gypsum is ground to flour it passes into another chain elevator and is carried to the top of the second story into the storage bin located just over the kettle. Figure 18 represents the ordinary type of bucket elevator used in the gypsum mills. Some of the new mills are using a blower and air blast to drive the gypsum to the upper portion of the mill. This is a new method, and there seems to be some opposition to its use on the part of certain operators.

The ground gypsum is run slowly from the storage bin into the calcining kettle, which is kept at a temperature of 212° F., or over, taking about one hour and a half to fill it to a depth of five feet. These kettles, as shown in Figures 19 and 20, are constructed of boiler steel three-eighths of an inch thick, and are usually eight feet in diameter and six to eight feet deep. They are set like a boiler upon a stone or brick base, and surrounded by a wall of stone about two feet thick with an air

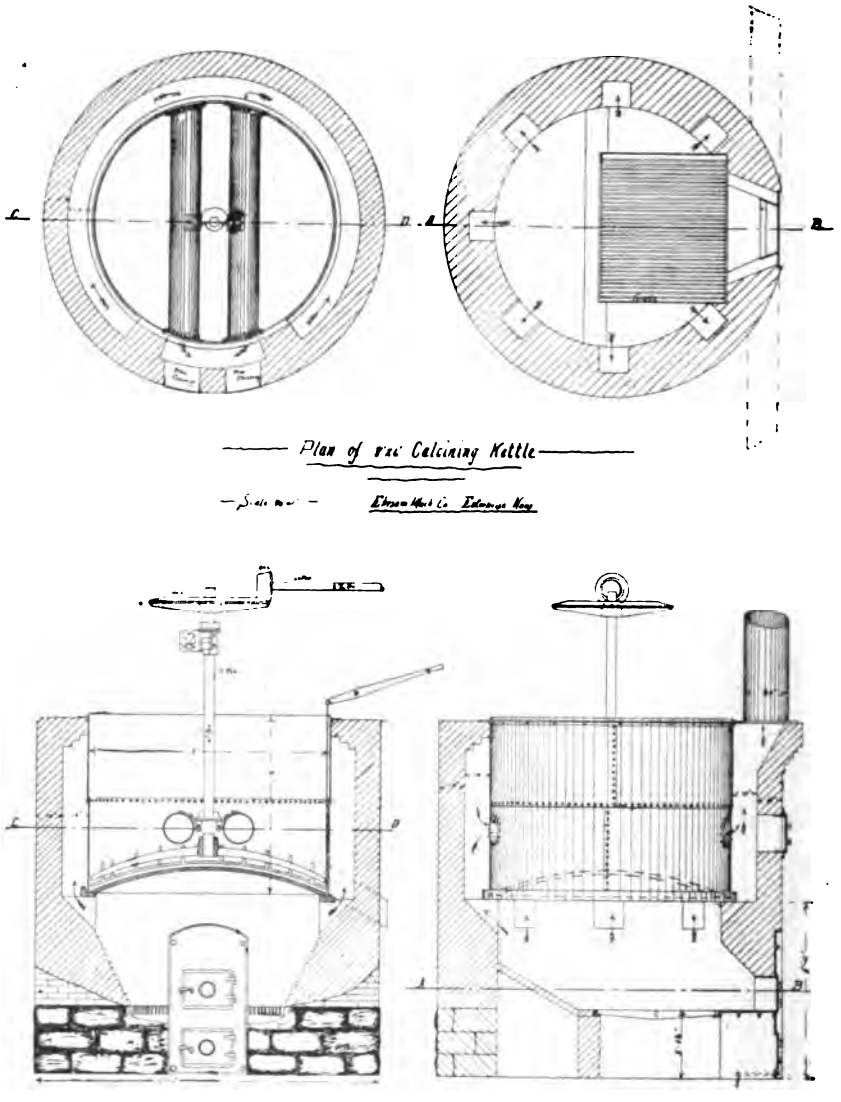


FIG. 19. Gypsum Calcining Kettle (in sections).

space between. The kettle bottom is convex upward and made of steel five-eighths inch in thickness. Such a kettle will hold seven and one-half tons of ground rock or earth. The gypsum is constantly stirred on the bottom of the kettle by two revolv-

ing arms with disks fastened to them, in order to keep the material from burning on the bottom. These arms are fastened to a four-inch vertical shaft which is driven by a five-foot horizontal crown wheel, set in motion by a one-foot vertical pinion wheel attached to the power shaft. It takes from ten to twenty-five horse power to run this stirrer, and sometimes, if plaster is run too rapidly into the kettle, the resistance is sufficient to break the teeth or cogs from the pinion wheel. The stirrer makes about fifteen revolutions per minute.

The kettle has two or four flues passing through, as shown in Figures 19 and 20. The heat comes up under the kettle as shown in lower part of Figure 19 and passes through the air space at side and then through the flues out into the air space on the other side and out through the chimney.

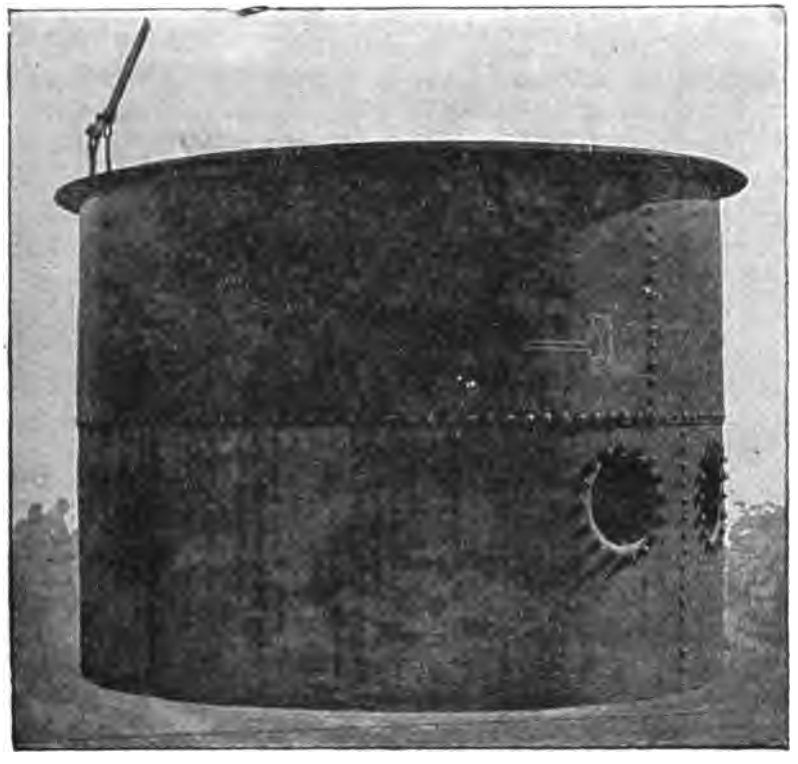


FIG. 20. Gypsum Calcining Kettle (outside).

In an hour after the kettle is filled the temperature reaches 230° F. and the mass is seen to be boiling vigorously as the water is driven off and out through the vapor stacks above. When the temperature increases to 270° F. (132° C.) the gypsum settles down solid, leaving twelve to sixteen inches of vacant space at the top, and the steam ceases to rise. At 280° or 290° F. (138° to 143° C.) the mass boils again, often throwing part of the material over the edge of the kettle. When a temperature of near 350° F. (177° C.) is reached, the plaster is rapidly withdrawn through a gate near the kettle bottom controlled by a lever above, as shown in Figures 19 and 20, into a fire-proof bin on the ground, and the kettle is refilled.

It is a difficult matter to tell the exact temperatures in a gypsum kettle. The usual method is to attach a thermometer to a long stick, and insert this through a door at the top of the kettle. After leaving the thermometer in the plaster a few minutes it is drawn up and read, but it is difficult to get the reading before the mercury column has dropped somewhat. Gypsum plaster is a good non-conductor of heat, and it clings to the cooler thermometer placed in the mass, and so causes the instrument to record a lower temperature.

In some mills a long tube thermometer is kept in the plaster, with the register projecting out of the kettle. This obviates the difficulty of thermometer cooling while it is being read, but the plaster adheres to the tube below, and so gives a lower reading.

In the other mills electrical wires run from the kettle to an automatic registering thermometer which is said to give good results. These records are filed away, and any objection to the plaster may be explained by the temperature record, and so may be corrected in other kettles. The expert calciners, however, depend more upon the appearance of the plaster in the kettle than upon thermometer readings.

The whole process takes about two and one-half hours, and there is a loss of weight in the gypsum of twenty per cent., due to the loss of water. Three kettles are usually burned in a day, and these require 1400 pounds of the best coal. Poor coals do not give sufficient heating power even when used in large quan-

tities. Weir-Pittsburg coal and coals from Colorado and Arkansas are the favorite fuels in the Kansas gypsum fields.

The great objection to the present kettle system of calcining gypsum is the great amount of heat required to calcine the mass of cold gypsum thrown into a kettle with thick steel bottom. Much heat is wasted by radiation from the kettle. Another objection is the large horse-power required to stir this mass of gypsum, and so keep it from overburning at the bottom. The great heat required tends to warp and burn out the kettle bottoms, which are heavy and expensive to replace. The methods of calcining gypsum have not improved much recently, and it would appear that there is room for improvement. The improvements made are looked upon with distrust. Kettles have been invented in the last few years for continuous calcining, and the product made was of good quality; but when the method of burning was discovered, the dealers made claims for rebate on the plaster, claiming it was not satisfactory. Tests on these plasters are said to have shown they were of good quality. It is to be hoped that these prejudices will be removed, and that plaster machinery will improve as machinery in other lines has improved.

THE MULVANE PLANT.

The Mulvane plant is the most recently constructed one in the state, having begun operations about January 1, 1899. In some respects, also, it is the most nearly an ideal type of a plant known in the West, as it combines to a high degree the latest devices for labor saving and for conveniences in handling the raw material and the finished product.

The plant, of two kettle capacity, is located immediately at the mines, with a switch from the Augusta branch of the Atchison, Topeka & Santa Fe railway passing alongside the buildings. A little stream cuts through the gypsum deposit, leaving the larger and better material on the south bank, with a considerable amount on the north. The buildings, three in number, are located on the north side of the stream; and are the calcining building, the power house, and the warehouse, to the former of which is attached a coal shed on the east (12 by 48

feet), and a shed on the south (30 by 96 feet) for storing the raw material. They are arranged in a north and south line, with a fifty-foot space between them, excepting that the coal shed approaches more closely to the power house. See Plate XXIX for an illustration of this plant.

Plate XXX shows these buildings in ground plan, Figures 4, 5, and 6, and the calcining building and power house in elevation, drawn on a larger scale, Figures 1, 2, and 3. The calcining building is 30 by 34 feet, with a coal shed at the east end 12 by 48 feet.

Figure 4 shows the location of the two kettles with the masonry walls surrounding them and the hot-pits to the rear, into which the plaster runs directly from the kettles. It also shows the position of the main drive wheel for propelling the scrapers, and the tunnel for drawing the raw material from the shed to the base of the elevator which elevates it for filling the kettles. Figure 1 is a side elevation of the same building, and Figure 2 an end elevation, each drawn to double the scale of Figure 4. Figure 1 shows the details of the elevator for lifting the raw material, of the suction fan for carrying the calcined plaster from the hot-pits to the receivers at the top of the building, of the bolts near the top where the plaster is sifted to exclude all coarse material, and of the south end of the auger conveyor which carries the sifted material across to the warehouse. It also shows the arrangement of the drive wheels propelled by the rope belting from the power house, and how motion is conveyed to the various parts of the machinery from these two main drive wheels.

Figure 2 shows in a different section the interior of the calcining building with the arrangement for propelling the scrapers, and different wheels and pulleys used in giving motion to the lifting and sifting and conveying machinery.

Figures 3 and 5 represent the power house, with the boiler, the heater, the water tank, the pumps, and the drive wheel in place. The machinery in the calcining building is propelled by a series of rope belting reaching from the power house.

Figure 6 represents the ground plan of the warehouse, shops,

etc. In the upper part of this building the mixer is placed, a machine which thoroughly mixes the plaster with fiber, so that when it is sent into the market the fiber is already mixed through the plaster. This building is placed immediately on the ground, with the floor of the ware room resting on timbers which lie directly on the ground. In this way the great load of the large stock will be readily supported and no joists or framework will be giving way under the continuous strain. This point is one of great importance. In some of the larger warehouses of the state the floor is supported by heavy framework beneath. Such a framework is costly, and frequently the supports give way under the continued strain of a large supply of stock, and repairs have to be made.

The Mulvane plant has mechanical appliances for handling both the raw material and the finished product to a greater extent than any other plant known in the state as they now are. The arrangement for hauling the gypsum earth to the mine is similar in some respects to that employed elsewhere, but differs slightly from anything else known. At the mine, teams with scrapers carry the material to a short bridge under which a car is placed. As the scraper is unloaded the material falls immediately into the car. The Agatite plant at Dillon likewise has this same arrangement. A horse draws the car across the branch to within about 200 feet of the calcining building. This distance at Mulvane is very short, so that the total amounts to but little. Here a cable is hitched to the car, which is then drawn up an incline to the very attic of the shed, as shown in Figure 1. The car is then unloaded by pulling a lever, which causes the load to drop to the floor below. By this arrangement the large shed can readily be filled to the rafters if desired. The material is carried from this shed to the calcining furnace by means of a long belt plying in a tunnel under the shed, as shown at the bottom of the figure. Here through a small opening in the floor the material is shoveled directly on to the moving belt which deposits it at the bottom of the chain buckets in the calcining building. These buckets elevate it to a point a little higher than the top of the calcining furnace and

throw it directly into the kettle or onto the floor space near by at the pleasure of the operator. This elevating machinery is entirely under the control of the operator, so that it can be stopped or started at will.

When the calcining is completed and the plaster is run into the hot-pits, shown in Figures 1 and 4, the suction fan is started and the plaster is lifted through sheet-iron pipes into the receivers in the attic of the calcining building, shown in Figures 1 and 2. By this operation it is cooled to a normal temperature, so that no further steps are necessary in the cooling process. However, to avoid all possible danger from fire, the receivers are made of heavy sheet iron. From here, by gravity, the plaster passes downward into the bolts where it is sifted, and from the bolts, again by gravity, passes into the auger conveyor, which carries it to the store room, Figure 6. Here it is delivered directly into the mixer, which is placed at the top of the building, but at an elevation a little less than that of the bolts in the calcining building. After passing through the mixer it is delivered, again by gravity, through the proper channels into the boxes or barrels for shipment.

In this way the one elevation by the suction fan in the calcining building is all that is necessary, gravity continuously assisting in the movements from that time until it is packed in the store room ready for shipment. Here the building is of the proper hight for convenience for loading directly into the car.

As will be seen by the above explanation the only handling of the material by the operators is with the scrapers at the mines and with shovels in the gypsum earth shed where the operator passes it through the opening in the floor on to the conveyor below. From that point until it is packed ready for shipment, the whole of the operation is performed by machinery.

The buildings of the Mulvane plant, see Plates XXIX and XXX, are not as expensive as those of some other plants in the state. This phase of the subject has already been referred to. Where a plant is constructed to manufacture plaster from the gypsum earth deposits it is practically certain that the life of

MULVANE CEMENT PLASTER MILLS.

the plant is limited, as the supply of material sooner or later is bound to be exhausted. Expensive buildings, under such circumstances, are certainly not the result of good business judgment. Where the plant uses the rock gypsum, the supply of which can be determined to a better advantage, the character of the buildings can be judged of much better, and can be made to correspond with the probable durability of the supply of the material.

GENERAL REQUIREMENTS OF A PLASTER MILL.

In connection with the discussion of the methods of manufacturing the different grades of plaster of Paris and cement plaster, it may be desirable to give a short discussion of the most important requirements for a modern plaster mill.

As has already been stated, the difference in the mode of manufacturing plaster from the rock gypsum and from the gypsum earth consists essentially in but two points: First, in crushing the rock gypsum so as to reduce it to a powder before calcining; and second, in mixing a little more retarder with the plaster before it is made into the mortar. As the trade demands a plaster ready for immediate use, the retarder is now universally mixed with the plaster at the factory. As the methods of crushing the rock gypsum and of grinding the plaster to a fine powder have already been described in considerable detail, nothing further need be added to such descriptions.

The essential requirements for a gypsum plaster mill may be enumerated as follows: First, the most convenient location possible, considering the character of the grounds around the mine and the proximity of the mine to one or more railroad lines; second, the proper arrangement of the buildings with reference to each other, having regard for the cost of the buildings, the conveniences afforded by their arrangement, and the safeguards against fire, etc.; and third, the internal arrangement of calciners and machinery.

Location of Mills, etc.

The exact location of a plaster mill is often a difficult question to decide. When the mines are some distance from a rail-

road, the raw material must either be hauled to the mills or the mills must be located at the mines and the finished product hauled to the road.

Few plaster companies have been organized in Kansas sufficiently strong to construct switches from the main line of a railroad out to the mines, when they were located several miles away. Or possibly a better way to state it is, that few companies have deemed it a wise business enterprise. Therefore at Medicine Lodge, Burns, and some other places, the mills have been located at the railroad and the raw material carted a distance of from four to eight miles from the mines to the mills. These operators consider the cost of hauling the extra weight of the raw material less than that of hauling the manufactured material one way and the fuel the other.

In some instances there are other considerations also which have a bearing on the subject. For example, at Medicine Lodge the mines are about six miles southwest of the city at the top of high hills and in undesirable places for residences of people engaged in the enterprise. With the mills placed at the mines it would necessitate the constant traveling back and forth of the employees and the proprietors, or the establishment of homes where they are not wanted. All such considerations should be carefully weighed before deciding on the location of a mill.

It may frequently happen that under one set of conditions the mills should be established at the railroad and the raw material hauled from the mines to the mills, while under another set of conditions the mills should be established at the mines and the fuel hauled out to the mills and the finished product hauled back to the railroad. When hauling is done in one direction only, the vehicles must travel empty half the time. They could therefore haul fuel from the railroad to the mills for almost nothing. The manufactured material weighs little more than two-thirds as much as the raw material. If, therefore, the conditions of living and of other conveniences around the mines are as favorable as at the railroad station, it will generally be found desirable to locate the mills at the mines

and let the same teams draw fuel from the railroad station which carry the finished plaster from the mills to the railroad. Acting on this principle, the Acme Cement Company established their mills at Rhodes, and haul the fuel from the road to the mills and the finished product from the mills to the road. So did also the Aluminite Company, whose mills are little more than half as far from the railway station as those at Rhodes.

In some instances a company would certainly be justified in building a switch from the nearest railroad point to the mines. This question is one which should be decided upon the merits of each individual case. If the deposit of gypsum is small, a company would not be justified in going to much expense to build a switch to the mines. Neither would one be justified in building a switch very many miles in length, unless the gypsum deposits were sufficiently large to warrant a strong company in contemplating the manufacture of plaster on a large scale for a long time. Also the character of the ground over which the road must pass is a factor of great importance, and which must be determined for each individual case. Railroad companies are generally willing to construct their own lines whenever the prospective amount of freight is sufficiently great.

Should the mines be too far away from railroads the present prices of gypsum cement plasters will not warrant the establishment of mills, no matter how abundant the material may be. Different areas in Kansas at the present time are under just this series of conditions. This is most markedly the case in connection with the immense deposits of gypsum in Barber and Comanche counties. Were these same masses of material properly located with reference to fuel and shipping facilities, they would be the greatest bonanza known in the state, or in the Mississippi valley. But with markets as they are and the location as it is, so far from a railroad line and so far from the great centers where plaster is extensively used, these millions upon millions of tons of as good gypsum as is known in the world must remain comparatively untouched until conditions change so as to favor their consumption.

Other instances may occur where the mines are located near by the railroad line, and yet some distance away, so that a switch must be built or the product must be teamed. In most cases, if the deposit is sufficiently large, it would seem that the better way would be to build a switch to the mines and locate the mills at or near by the material to be used. This is particularly true where the surface is even, so that grading would be light. If a company is sufficiently strong to manufacture plaster at all, it is probable that it will furnish enough freight to justify a railroad in placing the ties and steel on a graded road-bed. The greater number of our mills in the state, excepting those already mentioned, have acted upon this principle, and have had switches constructed reaching the mines.

The Agatite Company's mill at Dillon is a noted exception to this. The mines are three-eighths of a mile from the railroad. Instead of building a switch down to the mines, the company located its mills at the railroad and built a horse-car track to the mines, and draws the raw material to the mills. To one who has not made a careful calculation of the expenses connected with such an enterprise it would seem that a considerable saving might have been made by building a railroad switch to the mines and locating the mills in a convenient position with reference to the gypsum earth deposits. In this particular case such a position could readily be found without removing the mills far enough from Dillon to require the erection of new residences for the employees and operators.

The American Cement Plaster Company, at Mulvane, have constructed their plant upon the principle that it is cheaper to bring the railroad to the mills than to locate the mills on the main line of the railroad. Accordingly, they have a switch reaching into their grounds, and have the mills located immediately at the mines.

Arrangement of Buildings, etc.

It is probable that different companies entertain different ideas regarding the desirability of the extent to which buildings should be erected for the establishment of plaster mills. At least one is led to such a conclusion by observing the char-

acter of the buildings of the different Kansas mills. If a general criticism should be offered, it is that they are too expensive. In several instances, at least, it is quite apparent that too much money has been invested in the buildings themselves. The process of manufacture is so simple that elaborate buildings are never required.

Again, it may be called a mooted question regarding the number of buildings to be employed, as with some mills the power house, the kettle house and the store house are all in one building, while at other mills two or more buildings are employed. The Western Plaster Company, of Chicago, has two enormously large buildings, so arranged that it would seem more than twice the amount of money has been invested in buildings that necessity would demand, and probably a much larger floor space is provided than is necessary. In Kansas the largest individual building at any mill is that of the Agatite Company, at Dillon. Here all the parts are kept in one building, a large structure with an enormous floor space, as well as a great volume of room overhead.

Internal Arrangements of Calciners and Machinery.

The operations to be performed in a gypsum cement plaster mill are: 1st, obtaining of the raw material; 2d, calcining the same; 3d, intimately mixing the plaster with fiber, as the markets now demand; 4th, packing the finished product in bags or barrels, ready for shipment; and 5th, storing the same ready for shipment. With mechanical devices as highly developed along other lines of manufacturing enterprises as they now are, it is desirable that a plaster factory should be constructed so that the handling of the material throughout all stages of the process should be done by machinery. There is no more reason for handling any of it by hand than there is for our common flouring mills to handle the grain by hand — an old process which is entirely unknown to modern milling. The material should be brought from the mine by mechanical appliances to the greatest possible extent. If it is rock gypsum, some handling will be necessary at the mines, as the mining methods require it. But after it is loaded into the car there is no reason, under

ordinary circumstances, why it need be touched by shovel or hand until it is packed ready for shipment.

If the material is the gypsum earth, even the mining operations could be conducted profitably by machinery. With the many dredging devices now used for lifting sand from the bottom of rivers, and the various steam shovels employed in the large brick factories for lifting the clay from the pits, and other similar devices, it would seem that the old-fashioned way of handling the gypsum earth by hand, or with team and scrapers, should be replaced by mechanical devices.

After the material reaches the mill, no matter in what form it comes, it can readily be passed through the crushers, filled into the calcining kettles, elevated from the hot-pits to the bolts, cooled by the process of elevation, carried from the bolts to the mixers, and from the mixers to the devices for packing, entirely by mechanical operations. So long as steam power remains cheaper than man power such mechanical devices will be desirable.

The method of cooling and elevating the hot plaster which gives the best satisfaction of any thus far employed is that of the suction pipe. A sheet-iron pipe ten or twelve inches in diameter has a strong current of air forced upwards through it by a fan. The lower end of the pipe should be telescopic in character, so that it can be lengthened downwards at will. The mouth of the pipe is placed just over the center of the upper surface of the hot plaster. The air current forced upwards sucks the fine powder up and carries it to any desired hight. As the volume of the plaster in the hot-pit decreases the pipe is extended downwards so that at all times it is within an eighth or a fourth of an inch of the surface of the plaster. Such a process saves a large amount of space, where the hot material otherwise must be left until it can cool, and saves a great amount of time, for the cooling is accomplished during the time that the elevation is effected. In mills where the suction pipe is not employed it is common to elevate the material with a belt-bucket elevator and allow it to fall through several feet and again elevate it for the purpose of cooling it, a process

which is tedious and expensive and requires unnecessary time and space.

The horizontal conveyors which seem to give the best satisfaction are the belt conveyor and the auger conveyor, appliances similar to those now extensively used in the great milling centers.

USE OF RETARDERS.

During the process of calcination, about one-half hour before the operation is completed, some manufacturers add a retarder, in order to hold back the time of setting of the plaster. Plaster made from gypsum rock will set in six to ten minutes, and retarders are added in sufficient amount to hold back the set for two to six hours, or in extreme cases for twenty-four hours, in order that the workmen may have time to spread the plaster on the wall and properly trowel it down. Various substances have been used for this purpose. In the earlier days of cement plaster glue water was added by the workman as he used the material; but this was troublesome, and often resulted in poor work from neglect to use the right amount or failure to thoroughly mix the parts. The trade demanded a plaster already retarded in a way that would give uniform results.

Citric acid was used for a time, in the proportion of about two pounds to the ton of plaster, but this was expensive, and the results were often uneven. Magnesian limes are known to set much more slowly than the pure calcareous limes, so it was thought that the addition of such magnesian limestone would retard the plaster of Paris, but this proved a failure. Sours and sweets form the worker's rule for retarders, and sorghum formed a cheap and successful retarder.

At the present day patent retarders are used, known as Challenge, Iola, Webster City, etc., and they are used commonly in the proportion of six to fifteen pounds to the ton. In the old days of the Romans, blood was used to retard the set of plaster of Paris, and to-day the organic material of tankage from packing-houses is found to bring about the desired results.

The writer has in his possession copies of patent specifications of nearly fifty of these patent retarders and a few are given here

for illustration. Patent number 291,508, of May, 1883, gives a mixture of plaster of Paris, glue, glycerin, sawdust, slacked lime. Patent number 446,604, of December, 1890, gives a mixture of beans, peas, lentils, slacked lime, carbonate of soda, and alkaline earth. Patent number 456,297, of March, 1891, gives a mixture of plaster of Paris, sawdust, slacked lime, sand, sugar, and carbonate of soda. Patent number 433,743, of October, 1889, gives a mixture of glue, oil or fat, muriatic acid, and sulphuric acid. Patent number 393,002, of April, 1888, gives a mixture of plaster of Paris, paper pulp, flour pack, sawdust, fiber, salt, and copperas. Patent number 458,742, of March, 1890, gives a mixture of oil meal or flax-seed, an alkali, and properly treated portions of hoof, horn, or feathers. Patent number 390,157, of February, 1888, gives a mixture of plaster of Paris, glue, sawdust, Irish moss, molasses, tartaric acid, whiting, and sand. Patent number 544,142, of March, 1893, gives a mixture of tankage of rendered fats. Patent number 558,435, of October, 1892, gives a mixture of plaster of Paris, furnace slag, slacked lime, hydraulic cement, flour of grain, and fiber.

The exact influence of the retarder upon the plaster is not known, but it seems to hold the water and so hinder the rapid crystallization of the plaster. Whether this weakens the cement plaster or not is a disputed question among architects and plasterers.

It is very doubtful whether a good mineral or organic retarder will injure the plaster. The fact that it hinders the set or crystallization of the plaster would lead to the inference that the plaster would not be injured, for it it merely delays the time, and the resulting crystal network would be as strong as though no retarder was there. Poor retarders, by their decay, would probably weaken the plaster, but where used in small amounts the effect should not be very great. The safe method would be to use good retarders, which are not subject to decay, and to use them in small amounts.

After the hot plaster passes from the kettle to the ground bin it remains about an hour to partially cool, and then it is raised to the second story. It is next bolted or screened in some way.

In some mills ordinary flour-bolting machines are used, while in others the plaster descends into a horizontal cylindrical reel, forty inches in diameter and ten feet long, slanting downward three-eighths of an inch to the foot. This is made of brass wire cloth about forty by forty meshes to the inch. The tailings or screenings, usually about one per cent. in amount, are carried back to the buhr mill and reground. The fine plaster is run into 100-pound sacks or 250-pound barrels and is ready for shipment. The plan of a modern equipped mill in a Kansas field is shown in Plate XXX.

The calcined plaster which sets in a few minutes, forming a clear white finish, is known as plaster of Paris. The plaster which sets slowly, whether retarded or not, is called *cement plaster*. When water is added to these plasters they more or less rapidly unite with it, setting into a firm, solid mass.

Hardening of Cement Plasters.

It has been known for some time that if gypsum stone is heated and thrown into a ten per cent. solution of alum for a few minutes, and then heated again to redness, the plaster on setting is very much harder than the ordinary plasters.

Payen, as stated before, in his sixth principle, thought the hardening was due to the formation of a double sulphate of potash and lime. Landrin analyzed the alum plasters with the following results:

Landrin's Analysis of Alum Plasters.

ELEMENTS.	French cement.	English cements.		Stucco.
		1.	2.	
Sulphate of lime	96.75	98.19	98.02	98.55
Carbonate of lime	1.05	0.41	0.37	0.36
Silica	0.72	.....	0.42	0.51
Water	1.48	1.45	1.19	1.08

An examination of these figures shows that the alum cements are of great purity, and there is no trace of alumina or potash. Landrin explains the hardening of alum plasters as due to the reaction of sulphate of alumina and potash on the plaster stone, converting nearly all the carbonate of lime into the sulphate, or

gypsum. He tried mixtures of plaster with sulphates of soda, of potash, of ammonia; but on account of the amount of water in these salts, the results were not satisfactory at first. By changing the proportions of the salts so as to saturate the carbonate of lime in solution, the results were good, and a hard plaster was formed.

Landrin placed the crude gypsum in a ten per cent. solution of sulphuric acid for fifteen minutes, and then calcined it, and obtained a plaster of good set and hardness. Heat must be applied in sufficient amount to drive out all the sulphuric acid, and the best temperature was found to be between 600° and 700°F. Hydrochloric acid was used, but with poor results.

By the Greenwood hardening process, gypsum is burned in the usual way and then placed in an eight or ten per cent. solution of alum. After soaking for some minutes, the gypsum is drained and dried in the air and burned again at a dull red heat, but not above this temperature.

Keene's patent cement is made by drying a mixture of plaster of Paris with one part borax, one part cream of tartar, and eighteen parts of water. The mixture is burned at a low red heat for six hours.

Parian cement is made from gypsum hardened by means of borax. One part of borax is dissolved in nine parts of water, and the gypsum is treated with the solution. Sometimes one part of cream of tartar is added to the solution, with good results.

Attempts have been made to harden the gypsum with water glass solution, but it is not always satisfactory.

Landrin, in his experiments, found that lime had great influence on the plasters. By mixing lime with the plaster in different proportions he obtained plaster which set regularly and became very hard and took a high polish. He states that it is better not to use over ten per cent. of lime. Landrin's explanation for this change is that the lime in contact with water sets free heat, which evaporates the quantity of water not necessary to bring the hydrate plaster back to its original gypsum state, with its two molecules of water. The carbonic acid of

the air then carbonates, little by little, the excess of lime in the plaster, giving increased solidity and hardness to the plaster.

Kaur and Knop hardened plaster casts by sponging the surface with one part potassium hydrate with milk whey free from fatty matter. Four parts of this mixture were added to a syrupy solution of potassium silicate, and the result was much harder casts.

The hardened cement plaster is made at one mill in Kansas, at the Best Brothers' mill, at Medicine Lodge (see Plate XXV). The gypsum blocks are burned in the kiln and then treated with a secret solution and reburned. This plaster withstands a crushing force of 3000 pounds and a tensile strain of 698 pounds after seven days in air. It is claimed to be equal to the imported Keene's cement and superior to Portland cement for plastering purposes or for laying dry walls. This cement is not used much in Kansas, but has been received with favor in the eastern cities.

Hardening of Gypsum Blocks.[42]

Experiments have been make from time to time on hardening the soft gypsum stone. Many of these have been successful, but they have not attracted much attention. Renewed interest has been taken in this line of work in the last few years. A company in Chicago have hardened gypsum for inside finish for some of the public buildings in that city. At the present time a strong company is organized to build a mill in Colorado for the purpose of hardening gypsum and supplying it to the trade for inside ornamental finish to take the place of onyx and marble. They claim that the material is as durable as marble and can be supplied very much cheaper. The specimens which they have already treated show that the product has very much the appearance of marble, and there is without doubt a good future for this new industry. The process used by the Colorado company is a secret one and little information can be obtained about it.

Some processes for hardening gypsum have been patented

42. Mr. C. C. Quincy, of Chicago, has furnished the writer with the copies of patent specifications in this section and of retarders already given.

during the past four years. Patent number 549,151, filed December, 1894, by Mr. Geo. W. Parker, formerly of San Francisco, is entitled "Process of Treating Gypsum Rock to Imitate Chalcedony." The claim is as follows:

"The process of treating gypsum rock to represent chalcedony consists in first completely dehydrating the rock by the action of hot air, next allowing the now porous rock to absorb a solution of sulphate of iron, nitric acid and potassium sulpho-cyanide, after which immersing in a solution of aluminum sulphate [$Al_2(SO_4)_3$] for fifteen hours, next expose to air and then polish as set forth."

Patent number 588,287, of August, 1897, by Geo. W. Parker, of Grand Rapids, Michigan, (filed October 18, 1895; renewed July 10, 1897) is entitled "Gypsum Rock to Imitate Marble." The claim is:

"The process of treating gypsum rock which consists in eliminating the moisture from the rock by the action of hot air, then removing the then hot calcium sulphate into a closed compartment charged with the fumes of ammonia and then immediately immersing the cool rock in a warm solution of aluminum sulphate until the pores are filled, as set forth."

Hardened gypsum treated with stearic acid or with paraffine, and polished, resembles meerschaum, and it is used for cheap pipes. Sometimes a coloring solution of gamboge is added to complete the resemblance.[43] Wagner also records that Fissot made artificial stone from gypsum by burning and immersion in water first for a half minute, after which it was exposed to the air and then again immersed for two or three minutes, when the block appeared as hardened stone.

Uses of Gypsum.

Gypsum in its ground, uncalcined state is used as land plaster for fertilizer. Its value in this connection is much disputed and unsettled, and the subject will be discussed in the next chapter. In many states a large portion of the gypsum is thus used; but in this state only 560 tons out of nearly 65,000 tons in 1894 were ground into land plaster, and still less since that time.

Land plaster, on account of its absorptive properties, is valuable around houses and stables as a disinfectant. It readily takes up the offensive odors, and should be used much more than it is, around barns. The plaster absorbs especially the

43. Wagner, Chemical Technology, p. 333, 1889.

ammonia in such places and fixes it, making a very valuable fertilizer. On account of its cheapness and convenience it is a wonder that more of the land plaster is not sold. Our farmers should certainly give it a trial, and they will be pleased with the results.

Another use of the ground, uncalcined gypsum, which is not to be so highly recommended, is its use as an adulterant. Gypsum has been found to have a large use in this respect, as has been discovered in the various states where pure-food laws have been enforced, and where their chemists have made careful analyses of the various foods and medicines. It is found in flour, sugar, baking-powder, and other compounds. A very considerable amount is sometimes taken to cure chills and fever in its mixture with quinine. The land plaster has been used as an adulterant for white lead, where it is claimed to be beneficial. For these various purposes the plaster is sold under the name *terra alba*.

When gypsum is calcined it is known as plaster of Paris. The finer grades are sold as dental plaster and as plaster of Paris for casts and moulds. It is also used for white finish on walls of buildings. Calcined gypsum has been used for these purposes from a very early day.

The manufacture of the slow setting or cement plasters has been regarded as a comparatively new departure in the industry; but when Doctor Wallace[44] made analyses of the cements used in the great pyramid of Cheops, supposed to have been erected about 5000 years ago, these were found to be very closely related to our cement plasters, as shown in the analyses below:

ELEMENTS.	Inside of pyramid.	Outside of pyramid.	Cement plaster.	Kansas cement plaster.[45]
Sulphate of lime (gypsum)	81.50 per cent.	82.89	78.41	83.55
Carbonate of lime	9.47 "	9.80	10.79	3.07
Carbonate of magnesia	0.59 "	0.79	1.05	1.47
Silica	5.30 "	4.30	7.82	4.27
Alumina	2.41 "	3.00	1.93	0.47
Iron oxides	0.25 "	0.21		
Water	.....	.....	.....	6.67
Totals	99.52 per cent.	100.99	100.00	99.50

44. Thorpe, Dictionary of Applied Chemistry, Vol. 1, on Cements.

45. Roman cement plaster, Springvale, Kan. Analysis by E. H. S. Bailey.

Most of the gypsum material in Kansas is manufactured into the cement plasters, and the industry has been especially developed in this state probably on account of the fine deposits of gypsum earth which make a plaster of most excellent quality. Improvements are constantly being made and the industry is rapidly growing.

A cement plaster is a plaster which sets in two to twenty-four hours and reaches a considerable degree of hardness. Ordinary plaster of Paris, as we have seen, sets in a few minutes, and such material may have the set held back by the use of the proper retarders.

In general, when gypsum plaster sets it goes back to its original chemical composition, as has been indicated. Some dealers have taken advantage of this chemical principle, and have argued that this was also a physical law, and that the earth plasters on setting would go back to their original condition of dirt, or, as they choose to call it, rotten gypsum. Now in our discussion of the secondary deposits of gypsum, it was clearly shown that the gypsum earth was in no sense rotten or decayed gypsum, but it was dissolved from the rock and precipitated again, so that physically its structure was the true crystalline gypsum structure.

There is no basis whatever for this claim against the earth plasters, and the sooner dealers cease to use that argument the better it will be for their own trade. Whether such plasters are better or worse than the ordinary retarded rock plasters is for the trade to determine, mainly by long experience. Laboratory experiments do not solve that problem, and the plasters have not been used long enough to settle the problem. As far as the writer has been able to determine by actual experiment and by an examination of the plasters in buildings, and personal conversation with practical plasterers, the gypsum earth plasters and properly retarded rock plasters are both good, and are both popular.

Sometimes mistakes have been made in the burning of both kinds of plaster, and the resulting work with them was unsatisfactory. So if poor plaster is found on the walls of a build-

ing, it is not conclusive to say that the retarder used with the rock or any impurities in the gypsum earth were at fault. The conditions of calcining and the conditions of mixing and working by the plasterer must also be investigated.

Inexperienced calciners who depend wholly on a thermometer plunged at times into the kettle may make a very poor plaster from the very best materials. The Kansas calciners seem to understand their business, and we have in this state men who cannot be surpassed for this work. It is interesting to note in this connection that Kansas plasters stand in great favor in the east, even where they come under the disadvantage of lower freight-rates from mills located nearer these markets.

The gypsum cement plasters are displacing the old lime plasters in all the larger buildings and in many private residences. The advantages of such plasters are as follows: Being a good non-conductor of heat, the cement plaster is valuable in fire-proof buildings. It sets more rapidly and dries out much more rapidly than lime plaster, so that carpenters can follow the plasterers very soon after the plaster is placed on the walls, as can also the painters and paper hangers. Coloring matter can be mixed with the material in its preparation for mortar to produce any tint desired, as the gypsum plaster does not affect coloring matter as lime plaster does. The cement plaster requires less mortar than other plasters, and ceilings and walls thoroughly soaked from leaking and unprotected roofs have not been injured. It attains a high polish, and is used for wainscoting as a substitute for marble. Changes of temperature do not affect the walls, and therefore they do not chip or crack. The walls become dense and hard, and are vermin proof, so that the plaster is valuable for hospital walls.

The great objection to the use of cement plaster has been the greater expense. It costs about one-fourth more than ordinary lime plasters, but the results are so much better that it is bound to displace them more and more as its advantages become recognized.

Large amounts of cement plaster are used in the fire-proof buildings of our large cities. The Marquette building in Chicago

used 2634 tons of cement plaster; the Fair used 1800 tons; the New York Life building used 1280 tons; the Great Northern hotel used about 2000 tons.

Cement plasters have remarkable fire-proof properties, which are greatly increased by certain admixtures. Mixed with asbestos it has been used for plastering the inside of stove bowls. Calcined gypsum is mixed with finely ground cinders and poured between the iron joists in fire-proof buildings. Temporary plates are placed above and below the joists, giving a smooth under surface for the finishing coat of the ceilings of the lower stories, and a smooth upper surface on which the tile floor may be laid. This material is claimed to be thirty-five per cent. lighter, of twenty-five per cent. greater strength, and sixty per cent. cheaper than tiling which has long been used for this purpose. This material was used in this way in the government building at Omaha, and gave good satisfaction.

Mr. C. C. Quincy, of Chicago, has experimented on varying mixtures of asbestos and cement plaster for fire-proof material. He has now a mixture of these which has double the fire-proof qualities of the ordinary plaster and the hardness is not affected. This mixture is of special service around the steel beams in fire-proof buildings. In such buildings a small fire will sometimes be sufficient to warp these beams, and so twist the structure and injure very greatly its strength. This mixture, when subjected to the very severe test of heating to redness and then throwing water upon it, shows no change in hardness, and it is almost a perfect non-conductor. This is certainly a most important discovery, and will cause an increased demand for the gypsum plasters.

Gypsum plaster has been mixed with sawdust and molded into blocks which are then readily nailed to the wall for finish. They make a portable and very light finish. Calcined gypsum is used as part of a mixture for scagliola finish, in imitation of marble and onyx. It is colored and polished for inside interior finish with beautiful results.

Gypsum is used as filler in the manufacture of many fine papers. In the form of plaster of Paris, much of it is used by the

plate-glass factories to form a bed on which the glass is placed before polishing. It fits all the inequalities of the glass and so removes strain on the different parts of the plate. About 35,000 tons of plaster of Paris are used in this way in this country annually.

CHAPTER VII.

GYPSUM AS A FERTILIZER.

Use Among Ancient People.

In Germany and other parts of the old country, and in New York, Michigan, Ohio, and Virginia in this country, gypsum ground and uncalcined has long been used as a fertilizer. For this purpose it is sold under the name of land plaster. Its action on the soils has long been a disputed question and various theories have been advanced to explain the effects, many of which have been pure speculation.

Authentic examples in very considerable number are cited to prove that gypsum forms a good fertilizer on certain soils for certain crops. Other examples are cited where the plaster apparently had no effect whatever. As a result, many with the favorable experience have contended that gypsum is a universal fertilizer endowed with the most wonderful and mysterious life-giving power; while others with their failures under a different set of conditions, contend with equal persistence that gypsum possesses no value as a fertilizer under any conditions. Both sides base their opinions on practical experience and so are not to be moved in favor of their opponents. This explains why we find diametrically opposite statements in books supposed to be standard reference books on the subject of manures and fertilizers.

The use of gypsum as a fertilizer is very old, probably older than the making of plaster of Paris. Virgil writes of the value of impure gypsum on cultivated lands, and it was used by the early farmers of Britain and Lombardy.

The use of gypsum or land plaster as a fertilizer was recorded

in 1768 by a German clergyman by name of Mayer, of Kupferzell, in Hohenlohe, who noted that it had long been in use near Göttingen as a top dressing for young clover. Tscheffeli, the Swiss agriculturist, also used it with considerable success. After this time there were numerous experiments made to test its efficiency, and the implicit faith of the workers along this line gave the appearance of wonderful results.

Use in Maryland.

Thus, the early farmers of Maryland, according to Rees, used gypsum fertilizer with great success, and this writer states that

"It was most beneficial on high and sandy soils and had good effect on wheat, rye, barley, peas, potatoes, cabbage, clover, and all natural grass crops. The invariable result of the several experiments incontestably proves that there is a most powerful and subtle principle in this tasteless stone, but by what peculiar agency or combination it is capable of forcing vegetation in such an instantaneous and astonishing manner is a mystery which time reserves for others to unfold."

Even at the present day the writer has found a farmer who insists that repeated trials have shown him that gypsum placed upon land where potatoes were planted served to keep away the troublesome bugs. If this could only be proved a very important problem in potato culture would be solved, and much time and work be saved; but, unfortunately, observation classes this promising discovery with the preceding experience of the early Maryland farmers, and potato-bugs will have to be driven away with something besides gypsum.

Benjamin Franklin called attention to the value of gypsum as a fertilizer for grass, by sowing the land plaster in a clover field near one of the main roads in Pennsylvania so as to form the sentence "This has been plastered with gypsum," and the letters, it is said, could be detected readily by the hight and color of the clover where the gypsum had been sown.

Ruffin's Experiments.

Ruffin, in his book on Calcareous Manures,[46] written in 1832, states that

"There is no operation of nature heretofore less understood or of which the cause or agent seems so totally disproportioned to the effect as the enormous in-

46. Page 151.

crease of vegetable growth from a very small quantity of gypsum in circumstances favorable to its action. All other manures, whatever may be the nature of their action, require to be applied in quantities very far exceeding any bulk of crop expected from their use. But one bushel of gypsum spread over an acre of land fit for its action may add more than twenty times its own weight to a single crop of clover hay."

Johnson's Experiments.

In 1841 Mr. C. W. Johnson wrote for the Royal Agricultural Society of England a prize essay entitled "An Account of the Application of Gypsum as a Manure to the Artificial Grasses." He quotes in this paper a letter from Mr. James Barnard, a farmer in Hampshire, which gives some account of experiments with gypsum fertilizer, as follows:

"The soil of my farm is of a clayey nature and would be very stiff but for the number of stones there are in it. I have sown gypsum six or seven years and never on clover or saintfoin without satisfactory proof of its efficacy, having usually grown one-half ton more of hay per acre by its use. But the effect in 1838 was wonderful. I put on a bag (2½ cwt.) per acre on a two-year-old piece of saintfoin on the 1st of May with the plants very forward, just leaving the ground and coming to stalk; the gypsum had so increased the growth of the grass by the 9th of the same month that when crossing the land with a friend we observed the difference from one of the fields to the other; and at harvest time the extra produce of hay was quite one ton per acre. I then laid the field up and cut it again in October, when the effect of the gypsum was still more apparent, there being one and a quarter tons of hay per acre from the so dressed portion of the field and scarcely any on the remainder of the last. Cutting the saintfoin twice in one year and the enormous difference in the produce brought a great many persons to look at the field, who all declared they had never seen the like before. On the same piece this year (1839) I did not use gypsum, thinking it would be good enough without, and the difference was quite as great. I mowed twice the gypsumed portion, but there was nothing to cut on that which had not the gypsum. I can even see the effect where three years ago the gypsum was spread. I always leave a strip or two in every field to prove the effect. There is one thing more I wish to observe, that I never put in gypsum before the last week in April or first in May, and choose if possible a moist morning. I have not found much good effect from its application on either chalk or cold clay soils."

Boussingault's Experiments.

Boussingault, in 1841, spread gypsum over a clover field, and then analyzed the clover from the land where gypsum was spread and where it had not been spread. He found a great increase in amount of ash, which represented an increase in all the mineral constituents, but especially in lime, magnesia, and

potash. These experiments, carried on for two years on the same land, are given in the following table:[47]

Analysis of Clover.

	1841.		1842.	
	Land with gypsum.	No gypsum.	Land with gypsum.	No gypsum.
Ashes free from CO_2	270.0	113.0	280.0	97.0
Silica	28.1	22.7	10.4	12.7
Oxides (iron, manganese, and alumina)	2.7	1.4	?	0.6
Lime	79.4	32.2	102.8	32.2
Magnesia	18.1	8.6	28.5	7.1
Potash	95.6	26.7	97.2	28.6
Soda	2.4	1.4	0.8	2.8
Sulphuric acid	9.2	4.4	9.0	3.0
Phosphoric acid	24.2	11.0	22.9	7.0
Chlorine	10.3	4.6	8.4	3.0

This table gives the number of kilogrammes of the elements in clover from a hectare of ground, and it certainly shows that gypsum has had considerable effect on the clover. The great increase of potash shown by these analyses will be referred to again in connection with theories explaining action of gypsum on soils.

Wilson's Experiments.

In Wilson's Rural Encyclopedia, published in 1850, there is a summary of knowledge concerning the value of gypsum as fertilizer. He cites an experiment by a Mr. Smith in 1797, where six bushels of plaster to the acre were used in May on very pale, almost lifeless, white clover, and in two weeks, though there had been no rain, the clover was vigorously growing.

In another case given, part of a field was covered with gypsum and yielded 2226 pounds of herb and 316 pounds of seed. An equal sized tract without gypsum yielded only 839 pounds herb and 56 pounds of seed. According to one series of experiments a ton of hay additional to the acre was produced by use of gypsum.

47. Storer, Agricultural Chemistry, Vol. I, pp. 206-216, 1887.

In a series of questions and answers given in this old encyclopedia the following are of especial interest:

"1. Does plaster act favorably on artificial meadows? Forty-three answers, of which forty affirmative.

"2. Does it act favorably on artificial meadows the soil of which is very damp? Ten answers, all no.

"3. Will it supply the place of organic manure, or will a barren soil be converted into a fertile one by use of it? Seven answers, all no.

"4. Does gypsum sensibly increase the crops of cereals? Thirty-two answers, thirty negative."

Use in Virginia.

Boyd, in his Resources of South-western Virginia,[48] written in 1881, describes the use of gypsum as a fertilizer, and states:

"A farmer (Sexton) of Chatham Hill, Smyth county, bought two old worn-out farms which scarcely yielded nine bushels of corn to the acre, the soil being in a limestone belt and covered more or less with flint containing potash and soda, and doubtless some comminuted iron ore. At first he plowed four inches deep, sowing about one bushel of plaster to the acre; the next year he gauged his plows two inches deeper, sowing an increased quantity of plaster, the yield of corn—the crop he used—greatly augmenting; the third year he plowed two inches deeper, about eight inches altogether, using something less than two bushels of plaster to the acre, his crop at the end of the season being so great as to astonish him. The fourth year he plowed still deeper, bringing up the clay subsoil into contact, with an increased quantity per acre of plaster, making a yield at the end of the fourth season of 125 bushels of corn per acre on ground that had been really abandoned by the unenterprising people who had previously held it. This land when last seen seemed to be in a state of permanent fertility, for the corn on it in 1878 looked to the writer as though it would yield over 100 bushels to the acre."

Use in Ohio and Indiana.

The Western Plaster Works, of Chicago, have given records of the following experiments made within the past two or three years. The first comes from Ohio and the second from Indiana:

"The past four seasons have been very dry, and a large part, probably two-thirds, of the clover seed sown has been lost. I sowed a field of eight acres to oats, then sowed on clover seed and cross-harrowed. I then put on about a bushel of plaster to the acre. The result was a good yield of oats and a fine catch of clover that grew finely through the summer. The same week I seeded the eight-acre lot I seeded one of four acres, and in precisely the same manner, save that I sowed plaster on two acres of it; the other two acres went without plaster. Where the plaster was sown the clover grew as finely as in the eight-acre lot, while on that without plaster the yield of oats was much lighter, and what clover seeds sprouted nearly all died from the effects of drought."

48. Page 107.

From Indiana the following report was made:

"In 1892 I sowed plaster with corn, dropping a little plaster in each hill, and obtaining a large crop from the same. This year (1893) I put the same land to clover, with no plaster or other fertilizer, and now, wherever there was a hill of corn last year, the clover has grown six inches higher than the rest of the field."

Theories of the Action of Gypsum as a Fertilizer.

All these various experiments, with their favorable results, and very many others, which have been related by farmers who have made practical use of gypsum, show beyond any doubt that on certain soils and for certain crops, gypsum is a valuable fertilizer, but it is not valuable for all soils nor for all crops.

Various theories have been advanced to explain the action of gypsum on plants. Some of these are very crude and have long been set aside, but it will be interesting to recall them. Certain plants are benefited by use of gypsum plaster, and first the chemical composition of some of these plants will be examined. The examination of the ash of plants was made long ago, and formed the basis for a number of theories about the action of plaster on plants, especially for those theories which regarded gypsum as a direct element of plant food. The following tables are taken from Johnson's excellent book entitled "How Crops Grow," and give the parts in 1000:

ANALYSES OF PLANTS.

	Water	Nitrogen	Ash	Potash	Soda	Lime	Magnesia	Phosphoric acid	Sulphuric acid	Silica	Chlorine
Pasture grass	782	7.2	21.2	8.1	0.3	2.6	1.2	1.9	0.7	4.1	2.1
Red clover, young	860	6.0	14.0	5.1	0.3	3.9	1.3	1.7	0.3	0.4	0.6
" in bud	820	5.3	14.7	5.5	0.3	4.5	1.6	1.5	0.4	0.4	0.5
" in flower	800	4.8	13.7	4.4	0.3	4.8	1.5	1.3	0.4	0.4	0.5
Alfalfa (early flower)	740	7.2	19.2	4.5	0.3	8.5	0.9	1.6	1.1	1.8	0.6
White clover, in flower	805	5.6	14.3	3.1	1.0	4.3	1.4	1.8	1.1	0.6	0.6
Potato plant	750	3.4	9.5	5.8	0.3	0.3	0.5	1.6	0.6	0.2	0.3
Oats (grain)	143	17.6	26.7	4.8	0.4	1.0	1.9	6.8	0.5	10.5	0.3
Maize (grain)	144	16.0	12.4	3.7	0.1	0.3	1.9	5.7	0.1	0.3	0.2
Spring wheat (grain)	143	20.5	18.3	5.6	0.3	0.5	2.2	9.0	0.2	0.3	0.1
Winter wheat (grain)	144	20.8	16.8	5.2	0.3	0.5	2.0	7.9	0.1	0.3	0.1
Garden bean (seed)	150	39.0	27.4	12.1	0.4	1.5	2.1	9.7	1.1	0.2	0.3

THEORY OF DE CANDOLLE AND CHAPTAL.

An early theory to explain the action of gypsum on soils, very attractive and popular in its day, was that of De Candolle, who

looked upon gypsum as a stimulant to the leaves of plants. This theory, which became prevalent, stated[49] that "sulphate of lime acts as an irritant in favoring respiration and exhalation of plants."

Chaptal modified somewhat this theory and regarded the stimulation as due to the saline character given to the sap by the presence of gypsum, and as this mineral dissolved very slowly, it would gently stimulate and not irritate.

Gypsum rock is very porous and a good absorbent, so this property was long ago taken to explain its agricultural value. It was discovered that the atmosphere contained carbonate of ammonia which was carried down to the earth in rain water, and there it was thought to be held or fixed by gypsum. A good statement of this theory is given in Browne's American Muck Book,[50] written in 1851. The carbonate of ammonia acted on the sulphate of lime so as to form sulphate of ammonia and carbonate of lime. This prevented the escape of the volatile carbonate of ammonia back into the air. A computation was made which showed that 100 pounds of common unburned gypsum would fix or form twenty pounds of ammonia containing sixteen and one-half pounds of nitrogen. This would furnish a very large amount of valuable food to plants for their use; but now it is known that the amount of ammonia in the air is so small that it is very doubtful whether the amount so fixed by gypsum is even appreciable to the plants.

This theory was held and much elaborated by the chemist Liebig, who calculated that theoretically if forty pounds of gypsum were placed on a field, and only one-tenth of it entered plants as ammonia sulphate, there would be nitrogen enough for 100 pounds of hay, fifty pounds of wheat, or sixty pounds of clover.

STOCKHARDT'S THEORY.

Some have held that the gypsum fixed the ammonia formed within the soil by decaying vegetable matter; and further, that the gypsum hastened this decay. Davy tried a number of ex-

49. Annales de Chimie 55, p. 312.
50. Pages 68 to 75.

periments to disprove this latter statement, and he found that meat mixed with gypsum and allowed to stand for a considerable period of time showed not the slightest difference in time of putrefaction from meat not so treated. This theory is given in a brief summary by Stockhardt :[51]

"Gypsum acts chiefly through its sulphuric acid, which on the one side procures soluble ammonia from the humous constituent of the soil and furnishes this to the plant at a period when it is especially inclined to the production of leaves and stems; and on the other side, strengthens and increases the power of plants to absorb ammonia from the atmosphere, and this in greater proportion as they are more abundantly endowed with delicate and juicy leaves and are thus already fitted by nature to make a more abundant use of the atmosphere."

The fact that gypsum absorbs moisture readily was thought by some to explain its value. In wet seasons it took up the moisture and held it, and in dry seasons furnished the moisture to the plants. Some even thought that plaster had the power to draw moisture from below during periods of drought. Gypsum is a good absorbent of moisture, but it retains the liquid very closely, and while it may be of some value in this way, other substances, as ordinary lime, would be better.

DAVY'S THEORY.

Sir Humphrey Davy and others before and after his time have regarded gypsum as a direct source of plant food. Davy found that clover contained about two hundred weight per acre of sulphate of lime, and that this was the amount of gypsum which produced the greatest benefit on the soil, so he argued the gypsum entered the plant as sulphate of lime.

An examination of the table of plant composition given earlier in this chapter shows that lime and sulphuric acid are present in the plants benefited by gypsum. Other tables give sulphur as an element in plant ash rather than sulphuric acid. So sulphur was supposed to come from the gypsum which did not enter directly as plant food, but was first broken up into its parts. This action was supposed to depend on the presence of humous acids, whereby the gypsum was broken up into humate of lime and sulphuric acid. If too little humus were present

51. A Familiar Exposition of the Chemistry of Agriculture, p. 226, 1855.

this action would not take place, and on such soils gypsum would be of no value; if too much humus, the action would be rapid, setting free so much sulphuric acid that it would corrode the roots of plants and so prove injurious. The lime of plants shown in the table given was supposed by many to result from the decomposition of gypsum.

The sulphur of plants probably comes from other sulphates more easily decomposed than gypsum, though a portion may result from this mineral. Most of the lime is from other compounds, especially the carbonate of lime, which is readily soluble.

RECENT THEORY OF STORER.

Gypsum is now thought to act as a fertilizer of soils in three ways, one mechanical and two chemical.

First, lime is known to flocculate loose soils; that is, collect together the loose particles and make the soil more granular. This may be illustrated by placing lime in a muddy liquid, and the mud will flocculate and settle to the bottom. Lime also has an opposite effect on tough clay soils, where it granulates them, breaking the soil up into finer portions. Gypsum, as a lime salt, appears to act to a small extent in these ways and so improves the mechanical condition of soils; but in this respect other lime compounds act more powerfully and more rapidly, and so would be better.

Second, Storer[52] has pointed out that gypsum has nearly one-half its weight in oxygen and gives this up to many substances, and so may act upon nitrogenous and carbonaceous substances in the soil.

Third and most important, it has been shown that gypsum decomposes the double silicates in the earth, setting free potash as a soluble sulphate. According to Storer the action is as follows:

$$\left.\begin{matrix} Al_2O_3 \\ CaO \\ K_2O \\ H_2O \end{matrix}\right\} \times SiO_2 + CaOSO_3 = \left.\begin{matrix} Al_2O_3 \\ CaO \\ CaO \\ H_2O \end{matrix}\right\} \times SiO_2 + K_2OSO_3$$

52. Chemistry of Agriculture, Vol. 1, pp. 206-216, 1887.

By this means the potash in solution reaches the roots of the plants. This method of supply is of especial advantage to the deep-rooted plants, as in the order Leguminosæ—the clovers, beans, etc., which contain a considerable percentage of potash in their tissues.

Soils with abundant potash would not need gypsum, and soils with no potash compounds would not be benefited in this respect by gypsum.

This is the most modern view of the chemical value of gypsum as a fertilizer, and one which is held by most of the modern agricultural chemists. Boussingault's experiments and analyses referred to a few pages back, showed an increase in the amount of potash on land which had been covered with gypsum. This increase is explained by this chemical theory of action of plaster setting potash free from insoluble potash silicates. Potash fertilizers are displacing gypsum somewhat, but plaster still remains a valuable and cheap fertilizer.

In our own state this feature of gypsum manufacture has not attracted much attention because of the natural fertility of the soils. Very little if any fertilizer is yet required by Kansas farmers. If the old theory of the moisture-absorption properties of gypsum was true, gypsum would be in great demand in many parts of Kansas, but gypsum cannot do the work of irrigation.

CHAPTER VIII.

ON THE CHEMISTRY OF GYPSUM, PLASTER OF PARIS, AND CEMENT PLASTER.

BY E. H. S. BAILEY.

Importance and Distribution of Gypsum.

The commercial values of gypsum deposits have been recognized from very early ages, and in most of the civilized countries. It is interesting to go back to some of the oldest structures standing at the present time and note that, in some cases, plaster of Paris is the cementing material. On account of its fineness, porosity, whiteness, and the readiness with which it sets when mixed with water, it has been a favorite material for construction, especially in countries where there is a small rainfall, and for interior decoration of portions of buildings not exposed to the weather.

Deposits of gypsum occur in many places in Europe, especially near Castalino, Italy, at Montmartre and Argentuil, near Paris, and at Derby, England. In the United States, gypsum is found in large quantities in Michigan, New York, Iowa, Kansas, Virginia, Louisiana, Ohio, California, Colorado, Texas, and Arkansas, and is found in other states in smaller quantities. For many years the immense gypsum deposits of the Dominion of Canada, especially Nova Scotia, have furnished the eastern states with this material in the form of "land plaster."

Formation of Gypsum Beds.

What conditions have rendered possible the deposition of gypsum? Without giving details as to the geological occurrence of gypsum, there are several methods by which it is possible to

account for the beds of gypsum rock and of gypsum sand. It should be stated at first that this mineral very frequently occurs in the vicinity of deposits of salt, calcium carbonate, and magnesium salts, and, in fact, frequently mixed with these materials. If we examine the composition of sea water, and that of an inland lake, it is evident that there is a relation between the composition of the saline water and that of these deposits.

COMPOSITION OF BRINES.

ELEMENTS.	Result in grains per gallon.		
	By O. D. Allen, Great Salt Lake.	By Von Biboa, Atlantic ocean.	By Herepaths, Dead Sea.
Sodium chloride (salt)	6,918.15	1,671.34	6,702.73
Potassium chloride	.....	.....	682.63
Ammonium chloride	.....	.....	3.35
Calcium chloride	[50.27 excess	of chlorine.]	1,376.75
Calcium carbonate	312.76	.....	.....
Magnesium chloride	869.40	199.66	4,457.23
Aluminum chloride	.....	.....	31.37
Iron chloride	.....	Trace.	1.50
Manganese chloride	.....	.....	3.35
Sodium bromide	.....	31.16	156.53
Potassium sulphate	.....	108.46	.....
Magnesium sulphate	543.58	34.99	.....
Lime sulphate	49.04	93.30	38.07
Organic matter	.....	.....	34.59
Totals	.....	2,138.91	13,488.10
Specific gravity	.....	1.0275	1.17205

It is evident that the material in the ocean or in a sea or lake which has no outlet is obtained from the waters that continually run into it, and by evaporation only the water goes off and the tendency is continually to become more concentrated. All this material has then been picked up by the water in its excursions over and through the rocks and soil. Sometimes it has been deposited on the earth in immense layers and then we have perhaps a deposit of salt or gypsum. If water runs through the deposit of salt it becomes impregnated with the salt, and the brine thus produced can be utilized commercially for the manufacture of salt. In Hutchinson, and other places in this state, there are such brines, obtained by pumping water into the wells that have been bored in the salt beds. An analysis of

one of the Hutchinson brines made in the laboratory of the University shows that it has the following composition, expressed in parts per 1000:

ANALYSIS OF HUTCHINSON BRINES.

Sodium chloride	273.560
Insoluble residue	.025
Calcium sulphate	5.855
Magnesum chloride	2.450
Calcium chloride	.226
Water (by difference)	717.884
Total	1000.

In regard to the composition of calcium sulphate, a late authority,[53] says: "This substance was known from early times as a mineral closely resembling calc-spar, because like the latter it became brittle on burning. In 1764 Pott described these two substances as being different earths, and stated that some chemists assumed that the substance artificially produced by the union of sulphuric acid with lime was gypsum, and termed it *gypsum artefactum*. In 1750 Marggraf showed that these two substances were identical."

"Gypsum is sparingly soluble in water, one part of $CaSO_4 + 2H_2O$ dissolving, according to Marignac,[54] at 0° C. in 415; at 18° in 368; at 24° in 378; at 32° in 371; at 38° in 368; at 41° in 370; and at 53° in 375 parts of water. The point of maximum solubility lies therefore between 32° and 41° C. In the presence of many other salts calcium sulphate dissolves more readily, probably owing to the formation of double salts. Thus, according to Anton, 1 part of gypsum dissolves in 122 parts of a saturated solution of sodium chloride. Gypsum is tolerably soluble in boiling hydrochloric and nitric acid, and separates out from the acid solution on cooling in glittering silky needles." From the above it may be seen that although some authors state that the presence of salt tends to precipitate the gypsum, really it assists greatly in the solution, and the analysis of the brine given above would seem to confirm this statement. The rule was long ago

53. Roscoe and Schorlemmer, Vol. II, p. 437.
54. Ann. Chim. Phys. 1874, (5) 1274.

established that in a mixture of several compounds, that which could form a precipitate first would first be formed, and it is evident here that the calcium sulphate is the most insoluble substance that can be formed.

Some substances are less soluble in water than others, and to this fact we owe many of the peculiarities of the deposits. Gypsum deposits in general, and especially those of Michigan, are discussed by L. L. Hubbard.[55] He calls attention to Ochsenius' theory of the methods of deposition of these substances that are found in sea water. With an enclosed sea we should have one kind of a deposit; one in which there would be first a layer of the least soluble substances, as for instance, calcium carbonate, which would be followed by a layer perhaps of calcium sulphate, as that is a little more soluble, and later would come a layer of sodium chloride, mixed with calcium sulphate, and finally the "bittern," containing bromides and some magnesium and potassium salts, would deposit last.

If the lake or inland sea were so situated that the water could flow over a bar in and out, the denser water would settle to the lower part of the lake and would not flow out but would gradually concentrate and drop its load of mineral. The more soluble salts would be carried out and gypsum and salt would be introduced with each influx of fresh water. In fact it is then a matter of specific gravity. At a specific gravity of 1.0506 to 1.1304 the calcium carbonate would deposit. This had probably been kept in solution by the excess of carbon dioxide, which has not before had a chance to escape. At a specific gravity of from 1.1304 to 1.22 calcium sulphate would be deposited. As the specific gravity increased above this the salt would be precipitated, and the substances still more soluble last. This process is analogous to that actually employed in the purification of brine to make salt. In this case the brine is heated in one end of the tank, quite near the fire, until it deposits its calcium sulphate and begins to precipitate salt, then it is allowed to run into the larger division of the pan, where as

55. Geological Survey of Michigan, Vol. V, Part II, p. 9, ff.

it concentrates the salt crystallizes out. It is evident that the mother liquor left after a long run will be rich in the most soluble salts of the brine.

"Some observations[56] have been made on the water of the Mediterranean Sea, where it has been noticed that at the Straits of Gibraltar there is an undercurrent flowing out and an upper current flowing back into the sea. The water of the Mediterranean contains, in proportion to its salt, $2\frac{1}{2}$ times as much $MgSO_4$ as that of the Atlantic, and this excess is supposed to be in the upper levels. It follows therefore that more of the upper layers, on concentration, can attain a density that will enable them to penetrate below the level of the bar. They will therefore glide over the lower zone, and giving way to the 'feed water' from the Atlantic, will pass out under it into the latter body."

"If this were applied to the salt and gypsum basins, we see that magnesium salts flow out, while gypsum and salt laden water flows in. As long as the specific gravity is constant then the deposit will be about the same in character.

"According to Usiglio, sea water, concentrated to one-half its volume, deposits a large part of its $CaCO_3$, but between this point and a further concentration to 19 per cent. of its original volume only traces of $CaCO_3$ deposit. At the latter point however another large precipitation of $CaCO_3$ takes place. The first precipitation begins gradually and ends abruptly, while the second precipitation begins abruptly and ends gradually. This is supposed to be due to the action of calcium sulphate on sodium carbonate. This would be represented by the equation:

$$Na_2CO_3+CaSO_4=CaCO_3+Na_2SO_4.$$

"If there is any substance in solution which is deposited between the specific gravities of the two degrees of concentration, it will lie between the two layers of $CaCO_3$. Since the gypsum is more soluble in salt water than in fresh, and since when ocean water concentrates double salts may be formed, as well as the NaCl, $CaCl_2$, Na_2SO_4, and $CaSO_4$, the sudden and well marked deposits of $CaSO_4$ might be due to the sudden dilution of the concentrated water, or by the addition to it of a quantity of

56. Id., Part II, p. 15.

Na_2SO_4 or $CaCl_2$. Winds, floods, or high tides, might cause the additional deposit of other substances, such as clay and siliceous material.

"In speaking of the occurrence of anhydrite, associated with gypsum, Ochsenius thinks it may be due to the fact that hydrous calcium sulphate, in solution with potassium salts, may exchange a part of its water for potassium sulphate in the formation of such salts as polyhalite, etc., and this change, by withdrawal of the water, results in the formation of anhydrite."

This occurrence of the anhydrite with the gypsum was noticed by Prof. G. E. Patrick[57] in the analysis of the Iowa rock.

Another method for the formation of gypsum has been suggested, and that is by the decomposition of calcium carbonate by means of iron and copper sulphates, or the materials that are found in clay shales.

Thus: $CaCO_3+FeSO_4=CaSO_4+FeCO_3$.

Even the iron sulphide (pyrite) that is so often found in shales would on oxidation yield a sulphate, which in turn might decompose the calcium carbonate.

Another method of formation, and one that can be readily seen at the present time, is the action of volcanic gases, containing sulphur dioxide, in the presence of oxidizing material, upon calcium carbonate.

A method that would account for the formation of the beds of "gypsite," or gypsum dirt, as it is sometimes called, would be by the solution of the calcium sulphate from the already existing rock by the percolation of water over the beds and its subsequent rising to the surface and spreading out as a shallow lake. It would be very easy to understand how some sand and clay, and even calcium and magnesium carbonate, could be mixed with this material, for the winds of the surrounding country, which would be probably denuded of vegetation from the character of the soil, would readily transport this material and deposit it in the lake. So from the solution of a comparatively pure gypsum rock we should have various grades of

57. Geological Survey of Iowa, Vol. III, p. 292.

gypsite, containing many substances foreign to the original gypsum rock. The very fact that there is no salt with such deposits, and that the more soluble magnesia salts are absent, would substantiate this theory of the formation of the gypsite. It should also be noticed, as Prof. G. P. Grimsley has already pointed out, that much of this deposit may be of recent date, and in fact the work of deposition may be going on at the present time in limited areas.

Composition of Native Gypsum.

The symbol for gypsum being $CaSO_4, 2H_2O$, it is evident that the theoretical composition is:

Calcium oxide (CaO)	32.60	per cent.
Sulphuric anhydride (SO_3)	46.50	"
Water (H_2O)	20.90	"
	100.	

Practically, of course, there is always some impurity in the rock, so we have all grades of material, as the following analyses show.

The covering of the pyramid of Cheops, as reported by Doctor Wallace,[58] has the following composition:

CEMENT USED IN THE PYRAMID OF CHEOPS.

	Exterior.	Interior.
Silica and insoluble material	4.30	5.30
Aluminum oxide	3.00	2.41
Iron oxide	0.21	0.25
Magnesium carbonate	0,79	0.59
Calcium carbonate	9.80	9.47
Hydrated calcium sulphate	82.86	81.50
Totals	100.99	99.52

This is evidently a manufactured and "set" plaster, and corresponds quite closely to many of the samples that have been analyzed in Kansas. The sample from the exterior would contain 65.67 per cent. of calcium sulphate. It must have been made from material not altogether pure, like the rock gypsum, but more like a recent deposit.

58. Dictionary of Applied Chemistry, Thorpe, Vol. I, page 468.

PLASTER OF PARIS FROM FRANCE.

Analysis by M. Durand-Claye.[59]

	No. 1.	No. 2.	No. 3.	No. 4.
Silica and insoluble residue	4.9	1.4	0.6	4.0
Iron and aluminum oxides	2.5	1.5	0.8	1.4
Magnesium carbonate	5.05	2.3	2.7	5.05
Calcium carbonate	10.2	9.9	2.4	14.1
Calcium sulphate	70.9	79.05	87.7	71.6
Water	6.45	5.85	5.8	3.85

ANALYSIS OF BOILER INCRUSTATIONS.

A good illustration of the fact that a hydrate similar to the calcined plaster may be formed from evaporation of sea water is found in the analysis of the boiler incrustation of an Atlantic steamer using sea water. Calculating the amount of each constituent in per cent. the results were:

Calcium carbonate	0.3
Iron oxide (ferric)	2.0
Water	5.8
Calcium sulphate	91.9
Total	100.

This compares closely with the theoretical amount as regards water and calcium sulphate.

Some specimens that have been analyzed from foreign localities have the following composition:

GYPSUM FROM FOREIGN LOCALITIES.

	Wienrode, by Jungst.	Osterode, by Hampe.	Albay (Philippines), by Trobe.
Silica and insoluble residue	2.80	0.15	6.43
Iron and aluminum oxides	0.60	.....	0.64
Calcium oxide	31.87	32.44	29.41
Sulphuric anhydride	45.76	46.61	44.19
Water	19.90	20.74	20.18
Totals	100.93	99.94	100.85

59. Dictionary of Applied Chemistry, Thorpe, Vol. I, page 473.

GYPSUM FROM NOVA SCOTIA.[61]

	No. 1.	No. 2.	No. 3.	No. 4.
Sulphuric acid	43.65	43.98	40.84	44.86
Water	.....	.....	18.47	20.02
Insoluble in acids	1.88	2.67	0.99	2.57
Undetermined	4.28	2.77	11.20	0.97
Hydrated sulphate of lime (gypsum)	94.84	94.56	87.81	96.46
Totals	100.	100.	100.	100.

GYPSUM FROM NEW YORK.

	Cayuga.[62]	Onondaga.[63]	
Hydrated calcium sulphate	74.09	64.53	73.92
Insoluble	6.05	11.17	4.64
Other matter, chiefly $CaCO_3$	19.86	24.27	21.44

The average of the New York plasters:

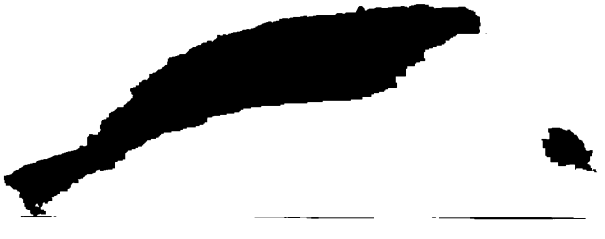
	Land plaster.[64]	Severance quarry.[65]
Hydrated calcium sulphate	65 to 75 per cent.	80 to 90 per cent.
Insoluble material	6 to 8 "	10 per cent. or less.
Calcium carbonate	18 to 28 "	Trace.
Magnesium carbonate	.....	5 per cent. or less.

GYPSUM FROM OHIO.

The following analysis is given of a sample from Ottawa county by Professor Orton:[66]

	Average sample.	Rotten plaster at surface.	Land plaster.
Water (H_2O)	20.14	20.00	19.70
Insoluble residue	0.68	0.46	0.91
Alumina (Al_2O_3)	0.16	0.29	0.60
Calcium oxide (CaO)	32.52	32.76	32.35
Magnesium oxide (MgO)	0.56	0.03	0.54
Sulphuric acid (SO_3)	45.56	46.20	46.38
Totals	99.62	99.74	100.48

61. Report Ct. Agric. Exp. Station, 1883, p. 62.
62. Id., 1884, page 75.
63. Id., 1883, page 62.
64. Id., 1882, page 50.
65. Bulletin N. Y. State Museum, Vol. III, page 81.
66. Geol. of Ohio, Vol. VI, 1888, pages 696-702.



GYPSUM FROM IOWA.

The following analyses are given of samples from Fort Dodge by G. E. Patrick :[67]

	Selected sample.	Top.	Middle.	Bottom.
Calcium sulphate	78.44	78.37	78.54	78.44
Water (calculated)	20.76	20.75	20.79	20.76
Insoluble residue	0.65	.....	.....	.....
Totals	99.85	99.12	99.33	99.20

GYPSUM FROM MICHIGAN.

Michigan alabaster, Western Plaster Works, Chicago; analysis by Geo. H. Ellis, who says that it is the finest grade of gypsum he ever analyzed :

Lime	32.88
Sulphuric acid	45.79
Water	20.98
Total	99.65

GYPSUM FROM CALIFORNIA.[68]

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Silica and insoluble residue	2.2	1.4	4.8	14.3	13.0	6.0
Calcium carbonate	9.0	9.7	12.0	3.9	....	22.0
Hydrated calcium sulphate (gypsum)	88.8	88.9	83.2	72.0	87.0	72.6
Other matter	....	....	....	9.8	....	....

No. 1, Coalinga. No. 2, Nevada Gypsum and Fertilizing Company. No. 3, Bakersfield mine. No. 4, Southern California. No. 5, San Francisco. No. 6, Los Angeles.

A more complete analysis from the same source is the following, from Lemore, Tulare county :

Silica and insoluble matter	10.78
Iron oxide	11.13
Aluminum oxide	.77
Magnesium oxide	.21
Sodium oxide	.84
Potassium oxide	1.24
Calcium sulphate	66.20
Water	8.83
	100.

67. Geological Survey of Iowa, Vol. III, p. 291.
68. Univ. of Cal. Exp. Station, 1891-'92.

Methods of Analysis.

Without giving the details of the analysis, with which all chemists are familiar, a few points should be noted. In dissolving the mineral, of which at least two grams is used, in hydrochloric acid and evaporating to dryness to render silica insoluble, when again dissolving in hydrochloric acid, there is danger that an error may be introduced by not treating the residue persistently enough with hot dilute hydrochloric acid. This is on account of the insolubility of calcium sulphate in concentrated acid, unless used in large quantities. It has been our practice to boil the so-called insoluble residue repeatedly with about a ten per cent. solution of acid, and to repeat this till the bulk of the residue does not diminish.

After the separation of silica, the filtrate is diluted to 500 c. c., and of this, 200 c. c. are used for the determination of the bases and 200 for sulphuric acid. This obviates making a second weighing of material for the acid. The precipitate of barium sulphate must be purified after weighing, by treating with dilute hydrochloric acid, filtering, and again weighing. It has been found advisable to precipitate the calcium oxalate twice, and to evaporate the filtrate in a beaker to dryness, on an iron plate, with an excess of nitric acid. By this means only a very small residue remains, as the ammonia salts have been changed to nitrate and decomposed into nitrous oxide and water, or have been driven off as sulphate or chloride. This leaves the magnesia salts with very little to interfere with their complete precipitation.

Water can be determined either by heating in an air bath at 200° C. to constant weight, or directly over a lamp turned so low that there shall be no danger of driving off carbon dioxide.

In cases where carbon dioxide has been determined, it has been done with greatest success by direct absorption in a potash bulb or in soda-lime, by the apparatus that is familiar to chemists. The apparatus in which the carbon dioxide is driven off and the amount calculated by loss in weight gives good results in the hands of one who has become sufficiently expert in its manipulation.

The methods of assembling the results will be referred to from time to time.

Kansas Gypsum—Localities.

Specimens have been examined from the following localities in Kansas:

I.—GYPSUM ROCK:

1. Blue Rapids, three samples.
2. Hope, two samples.
3. Vicinity of Dillon, two samples.
4. Medicine Lodge, one sample.
5. Solomon, two samples.

II.—GYPSITE (often called "dirt," or "gypsum earth"):

6. Dillon, two samples.
7. Beds south of Dillon, two samples.
8. Rhoades, five samples.
9. Salina, two samples.
10. Gypsum City, five samples.
11. Longford, two samples.
12. Mulvane, one sample.
13. Burns, one sample.

Some of the analyses in the following tables are from the series of analyses reported by E. H. S. Bailey and M. W. Whitten (Kansas University Quarterly, January, 1897); others from the work of Bailey and O. F. Stafford; yet others by Bailey and Prof. E. C. Franklin; some by Bailey and D. F. McFarland; and others are by the author.

GYPSUM ROCK FROM BLUE RAPIDS.[69]

The following analyses of the gypsum from this locality were made:

	Fowler's. No. 1.	Great Western. No. 2.	Winter's. No. 3.
Silica and insoluble residue	0.35	0.65	0.40
Iron and aluminum oxides	0.12	0.17	0.19
Calcium oxide	32.44	33.51	32.28
Magnesium oxide	0.12	0.19	0.17
Sulphuric anhydride	46.24	46.65	45.96
Water	20.52	18.84	20.36

69. Analyses by Dr. Edward Bartow.

It is possible that there were traces of carbon dioxide in these samples, and for the sake of comparison, calculating them with this in view, the probable combinations would appear as follows:

	No. 1.	No. 2.	No. 3.
Silica and insoluble residue	0.35	0.65	0.40
Iron and aluminum oxides	0.12	0.17	0.19
Magnesium carbonate	0.25	0.39	0.35
Calcium carbonate	0.10	1.53	0.25
Calcium sulphate	78.73	79.30	78.10
Water	20.52	18.84	20.36
Totals	100.07	100.88	99.65

ROCK FROM THE VICINITY OF DILLON.

	Small quarry south of Dillon.[70]	Four miles south of Dillon.[71]
Silica and insoluble residue	0.35	1.18
Iron and aluminum oxides	0.12	0.15
Magnesium carbonate	0.57	0.52
Calcium carbonate	0.56	0.36
Calcium sulphate	78.40	78.04
Water	19.96	20.00
Totals	99.96	100.25

These are extremely pure gypsum rocks as compared with some of those from the east, and contain a correspondingly high quantity of water.

GYPSUM FROM THE VICINITY OF HOPE.

Not far from Hope the rock has been used for the manufacture of "plaster" in the adjacent mill.

The three following samples[72] are from Hope: No. 1 is a sample from five cars at the entrance of Hope shaft; No. 2 is from a shaft west of Hope; and No. 3 is taken from boulders on a hill near Hope, and was formerly used at Hope mill.

70. Analysis by Bailey and Whitten.
71. Analysis by Bailey and Franklin.
72. Analysis by Bailey and Whitten.

	No. 1.	No. 2.	No. 3.
Silica and insoluble residue	0.52	0.34	0.41
Iron and aluminum oxides	0.26	0.16	0.29
Calcium oxide	32.28	32.64	32.53
Magnesium oxide	0.98	0.62	0.29
Sulphuric anhydride	44.61	45.28	46.03
Carbon dioxide (calculated)	1.90	1.42	0.56
Water	19.47	19.63	19.70
Totals	100.02	100.09	99.81

Calculating the above constituents as they probably exist in the rock, the result would be:

	No. 1.	No. 2.	No. 3.
Silica and insoluble residue	0.52	0.34	0.41
Iron and aluminum oxides	0.26	0.16	0.29
Magnesium carbonate	2.06	1.30	0.61
Calcium carbonate	1.87	1.68	0.55
Calcium sulphate	75.84	76.98	78.25
Water	19.47	19.63	19.70
Totals	100.02	100.09	99.81

MEDICINE LODGE GYPSUM.

A rock used by Best Brothers at their mill for the manufacture of cement has the following composition:[73]

Silica and insoluble residue	0.19
Iron and aluminum oxides	0.10
Calcium oxide	32.53
Magnesium oxide	0.16
Sulphuric anhydride	45.73
Carbon dioxide (calculated)	0.81
Water	20.46
Total	99.98

Calculating the above constituents as they probably exist in the rock, the result would be:

Silica and insoluble residue	0.19
Iron and aluminum oxides	0.10
Magnesium carbonate	0.34
Calcium carbonate	1.43
Calcium sulphate	77.46
Water	20.46
Total	99.98

73. Analysis by Bailey and Whitten.

The analysis shows that this is an extremely pure rock and well adapted to the purpose of making plaster of Paris.

GYPSUM FROM SOLOMON.

There are two samples[74] from the vicinity of Solomon mills. No. 1 is a rock from the mine at the mill; No. 2 is the rock that occurs about a quarter of a mile east of Solomon mills. This material is used in small quantities mixed with the material from the mine at the mill.

	No. 1.	No. 2.
Silica and insoluble residue	0.55	0.38
Iron and aluminum oxides	0.23	0.16
Calcium oxide	32.64	32.04
Magnesium oxide	0.22	0.46
Sulphuric anhydride	45.95	45.77
Carbon dioxide (calculated)	0.63	0.50
Water	19.54	20.37
Totals	99.76	99.68

According to the above analysis the probable composition of the rocks is as follows:

	No. 1.	No. 2.
Silica and insoluble residue	0.55	0.38
Iron and aluminum oxides	0.23	0.16
Magnesium carbonate	0.47	0.96
Calcium carbonate	0.86	.....
Calcium sulphate	78.11	77.81
Water	19.54	20.37
Totals	99.76	99.68

Calculating from sulphuric acid, the average per cent. of hydrated calcium sulphate (gypsum) in ten samples noticed above, from four localities, is 98.53. This means that the average of the Kansas rock known as gypsum contains only one and one-half per cent. of impurities. This is purer than the material used from Nova Scotia and New York, and compares favorably with other western samples.

74. Analysis by Bailey and Whitten.

Analyses of Gypsite (Gyspum Earth).

MARLOW, I. T.

A sample of the crude gypsite, from which "Royal" is made, has the following composition :[75]

Silica and insoluble residue	10.67
Iron and aluminum oxides	0.60
Calcium oxide	30.20
Magnesium oxide	0.51
Sulphuric anhydride	34.98
Carbon dioxide (calculated)	5.08
Water	16.59
Total	98.63

Combining the above constituents, the probable composition would be :

Silica and insoluble residue	10.67
Iron and aluminum oxides	0.60
Magnesium carbonate	1.10
Calcium carbonate	10.21
Calcium sulphate	59.46
Water	16.59
Total	98.63

GYPSITE FROM DILLON.

Gypsite used at the mills of the Salina Cement Plaster Company :[76]

Silica and insoluble residue	12.13
Iron and aluminum oxides	0.99
Calcium oxide	29.14
Magnesium	0.42
Sulphuric anhydride	37.49
Carbon dioxide (calculated)	2.03
Water	16.75
Total	98.95

After combining the above ingredients in the most probable compounds, the results would be as follows :

Silica and insoluble residue	12.13
Iron and aluminum oxides	0.99
Magnesium carbonate	0.88
Calcium carbonate	3.57
Calcium sulphate	64.63
Water	18.75
Total	98.95

75. Analysis by Bailey and Stafford.

76. Analysis by Bailey and Whitten.

Another sample of this material showed a per cent. of 6.49 of silica and insoluble residue, but this is evidently below the average of the deposit.

Gypsite from a bank about three miles south of Dillon, known as "Aluminite," and manufactured by the Dillon Cement Plaster Company, gives the following analysis :[77]

	78.	*79.*
Silica and insoluble residue	17.10	3.18
Iron and aluminum oxides	2.04	0.95
Calcium oxide	27.62	32.16
Magnesium oxide	0.59	0.15
Sulphuric anhydride	33.28	41.00
Carbon dioxide (calculated)	4.04	2.90
Water	15.16	19.44
Totals	99.83	99.29

If the constituents are combined as they probably exist in the sample :

	78.	*79.*
Silica and insoluble residue	17.10	3.18
Iron and aluminum oxides	2.04	0.95
Magnesium carbonate	1.24	0.33
Calcium carbonate	7.71	6.18
Calcium sulphate	56.58	69.70
Water	15.16	19.44
Totals	99.83	99.78

GYPSITE FROM RHOADES.

	80.	Four ft. from surface.[81]	Eight ft. from surface.[81]	Bottom of bed.[81]	Average of one acre.[81]
Silicia and insoluble residue	3.06	4.25	4.82	15.76	8.78
Iron and aluminum oxides	0.34	0.53	0.79	0.49	1.98
Magnesium carbonate	0.90	0.21	0.34	5.14	1.12
Calcium carbonate	11.03	3.56	4 52		7.25
Calcium sulphate	67.32	69.51	68.14	59.93	58.25
Water	17.24	20.82	20.41	18.64	20.66
Total	99.89	98.88	99.02	99.96	98.04

77. This was not an average sample, as a part of the bed was under water at the time it was taken.

78. Analysis by Bailey and Whitten.

79. Analysis by Bailey and Stafford.

80. Analysis by Bailey and Whitten.

81. Analysis by Paul Wilkinson.

CEMENT PLASTER (Manufactured).	From Rhoades.[81]	From Quanah, Tex.[82]	From Florence, Colo.[81]
Silica and insoluble residue	1.00	7.43	39.55
Iron and aluminum oxides	0.33	0.12	0.61
Magnesium carbonate	0.75	Trace.	0.54
Calcium carbonate	1.50	5.07	5.79
Calcium sulphate	88.50	78.66	46.99
Water	8.00	8.49	6.42
Totals	100.08	99.77	99.90

The analyses of four other samples[83] of the material used at the Rhoades mill will be of interest:

	No. 1.	No. 2.	No. 3.	No. 4.
Silica and insoluble residue	7.68	11.78	6.33	5.14
Iron and aluminum oxides	0.89	1.87	0.53	0.67
Calcium oxide	30.23	28.64	30.70	31.56
Magnesium oxide	0.88	0.48	0.42	0.53
Sulphuric anhydride	37.28	35.04	32.77	39.20
Carbon dioxide (calculated)	4.13	3.75	6.38	3.83
Water	17.77	18.25	19.23	19.95
Totals	98.86	99.81	96.36	100.88

No. 1 is the average of eight samples, taken from different parts of the bed and at depths of from $2\frac{1}{2}$ to $3\frac{1}{2}$ feet.

No. 2 is a sample from a deposit on the opposite side of the small stream.

No. 3 is a sample of material said by the manufacturer to be "material which does not make plaster of itself, but when mixed with the regular material acts as a retarder.

No. 4 is a sample said to be "average crude dirt, as generally used in manufacturing."

If the above constituents are combined as they probably exist in the material, the composition would be:

	No. 1.	No. 2.	No. 3.	No. 4.
Silica and insoluble residue	7.68	11.78	6.33	5.14
Iron and aluminum oxides	0.89	1.87	0.53	0.67
Magnesium carbonate	1.76	1.00	0.88	1.12
Calcium carbonate	7.39	7.37	13.68	7.36
Calcium sulphate	63.37	59.56	55.71	66.64
Water	17.77	18.25	19.23	19.95
Totals	98.86	99.81	96.36	100.88

81. Analysis by Paul Wilkinson. 82. Analysis by P. F. Nishkian, Kansas City.
83. Samples received from P. Wilkinson; analysis by Bailey and Stafford.

It will be noticed that with this method of combination the sample said not to make a good plaster by itself contains much more calcium carbonate than the others. Whether this retards the set because it takes the place of so much calcium sulphate, or whether it acts as a true retarder, as discussed farther over, would have to be determined by comparing a number of samples that were similar in other respects.

GYPSITE FROM SALINA.

Two samples received in 1892 were analyzed by Prof E. C. Franklin, with the following result:

	No. 1.	No. 2.
Silica and insoluble residue	34.35	9.73
Iron and aluminum oxides	4.11	0.78
Magnesium carbonate	10.52	trace.
Calcium carbonate	8.14	4.32
Calcium sulphate	34.38	68.29
Water (by difference)	8.50	16.88
Total	100.	100.

GYPSITE FROM LONGFORD.

This is used at the mill of the Salina Cement Plaster Company.[84]

Silica and insoluble residue	10.23
Iron and aluminum oxides	1.12
Calcium oxide	30.78
Magnesium oxide	0.45
Sulphuric anhydride	34.56
Carbon dioxide (calculated)	5.67
Water	17.10
Total	99.91

Combining the above constituents, the probable composition would be:

Silica and insoluble residue	10.23
Iron and aluminum oxides	1.12
Magnesium carbonate	0.94
Calcium carbonate	11.77
Calcium sulphate	58.75
Water	17.10
Total	99.91

84. Analysis by Bailey and Stafford.

Another sample from this locality contained 18.69 per cent. of insoluble matter and silica and 6.10 per cent. of calcium carbonate, but from a knowledge of the composition of a large number of other samples from the same deposit, the amount of insoluble material is evidently too high to represent the average.

GYPSITE FROM THE TINKLER DEPOSIT.

One sample of the crude material from this farm was analyzed.[85] It was formerly used at the mill in Gypsum City. The analysis is as follows:

Silica and insoluble residue	4.54
Iron and aluminum oxides	0.54
Calcium oxide	32.31
Magnesium oxide	0.28
Sulphuric anhydride	42.10
Carbon dioxide (calculated)	2.54
Water	17.82
Total	100.13

Calculating the above constituents as they probably exist in the rock, the result would be:

Silica and insoluble residue	4.54
Iron and aluminum oxides	0.54
Magnesium carbonate	0.59
Calcium carbonate	5.07
Calcium sulphate	71.57
Water	17.82
Total	100.13

The following analyses[86] have been made of the crude gypsite manufactured in Gypsum City by the Acme Company in 1892:

	Surface of bed.	Center of bed, 4 ft. below surface.	Average.	Quick setting dirt.
Silica and insoluble residue	13.50	7.65	3.62	15.08
Iron and aluminum oxides	1.05	0.52	0.45	0.44
Magnesium carbonate	0.76	0.63	0.34	7.02
Calcium carbonate	7.50	8.11	4.09	
Calcium sulphate	60.27	64.72	71.94	60.51
Water	17.05	18.39	19.87	17.46
Totals	100.13	100.02	100.31	100.51

85. Analysis by Bailey and Whitten.
86. Analysis by Paul Wilkinson.

Manufactured cement plaster from Gypsum City, 1892; Acme Company:[87]

	?	?	?	Four feet below surface.	Quick setting dirt.
Silica and insoluble residue	11.97	14.67	5.52	9.73	19.43
Iron and aluminum oxides	0.67	1.05	0.40	0.62	0.53
Magnesium carbonate	0.73	0.95	1.74	0.65 }	9.59
Calcium carbonate	8.11	10.07	12.00	11.30 }	
Calcium sulphate	71.43	66.91	74.43	72.42	64.42
Water	6.98	6.41	6.99	5.49	6.21
Totals	99.89	100.06	100.38	100.21	100.18

GYPSITE FROM BURNS, BUTLER COUNTY.

A sample, recently obtained, has the following composition:[88]

Silica and insoluble residue	2.31
Iron and aluminum oxides	0.37
Calcium oxides	34.52
Magnesium oxide	0.25
Sulphuric anhydride	39.95
Carbon dioxide (calculated)	5.42
Water	17.72
Total	100.54

If the above constituents are combined as they probably exist in the material, the results would be expressed thus:

Silica and insoluble residue	2.31
Iron and aluminum oxides	0.37
Magnesium carbonate	0.52
Calcium carbonate	11.71
Calcium sulphate	67.91
Water	17.72
Total	100.54

The sample appears to be of fine texture, and lighter in color than some. If it is an average sample, it contains less insoluble material than most of the beds, but considerable calcium carbonate.

GYPSITE FROM MULVANE.

Large deposits of gypsite have been discovered near Mulvane, and a mill of the most improved construction has been recently

87. Analysis by Paul Wilkinson.
88. Analysis by Bailey and McFarland.

erected to manufacture the material. The crude sample analyzed has the following composition:[89]

Silica and insoluble residue	2.17
Iron and aluminum oxides	0.24
Calcium oxide	32.42
Magnesium oxide	0.45
Sulphuric anhydride	44.18
Carbonic anhydride (calculated)	1.67
Water	19.40

Combining the above constituents as they probably exist in the crude material:

Silica and insoluble residue	2.17
Iron and aluminum oxides	0.24
Magnesium carbonate	0.95
Calcium carbonate	2.66
Calcium sulphate	75.11
Water	19.40
Total	100.53

Observations upon the Composition.

If we figure the composition of these samples from the sulphuric acid, and calling pure gypsum $CaSO_4+2H_2O$, the average per cent. in 20 samples of gypsite from this state would be 79.29. There is then an average of 20.71 per cent. of impurities, or substances not gypsum, in the material.

It has been contended that the other substances in this material add to its value, if not present in an excessive quantity. This is a difficult question to settle from a chemical standpoint, and indeed the advantage, if any, may be mechanical rather than chemical. It is, however, evident from reports on the setting of those samples containing considerable calcium carbonate, that this material tends to defer the setting. To what extent does it at the same time weaken the material? If there is no calcium oxide in the manufactured product, it would not seem probable that the action of the air would increase the hardness, as no carbon dioxide could be absorbed, as is the case with ordinary mortar. It has not been proved, although we have made

89. Analysis by Bailey and McFarland.

some experiments in this line, that there is any direct union between the silica and the calcium and magnesium. The cement plaster stands, in some respects, between ordinary mortar and hydraulic cement, and a much more extended study is necessary to determine all its properties.

In the above analyses the chemist will readily see that the sulphuric acid is combined with the calcium, and the remainder of the calcium with carbon dioxide, and all the magnesium with carbon dioxide. It will be evident that, with this distribution, in many cases there is a slight excess in the sum. This would usually be the case in the analysis of such material, if the alkalies and other substances, which are in small quantities, were determined. This seems to point to the fact that some of the calcium, and probably magnesium, is combined with the silica, and is decomposed in the process of getting the mineral into solution. This insoluble residue also represents both pure silica and some silicates that have escaped decomposition. Other experiments confirm this conclusion. These beds seem to consist of quite pure lime salts, with only a small admixture of either magnesium or iron and alumina.

The theoretical amount of water in the crude material, if it consists of absolutely pure gypsum, is 20.90 per cent.; this would agree with the formula $CaSO_4, 2H_2O$. As the commercial samples are always impure, the per cent. of water is lower, but a comparison shows that it is usually a little higher than the theoretical amount for a sample of that degree of purity. This would be accounted for by the fact that the air-dried sample is used for analysis, and that it retains some of the hygroscopic water. Thus, a sample of crude gypsite that contained 60.27 per cent. of calcium sulphate should contain 16.41 per cent. of water, but the analysis shows that it really contains 17.05 per cent., so the extra 0.64 per cent. is due to hygroscopic moisture. Had the sample been carefully dried for a sufficient length of time most of this would have been driven off. It is necessary, however, to use great care in the drying of the crude material, as water is driven off in small quantities at as low a temperature as 80° C., and, in fact, plaster of Paris may be

made after heating a long time at this temperature. However this may be, in a series like that shown under the head of "Manufacture of Plaster," it is easy to observe that a high per cent. of calcium sulphate means a high per cent. of water, while a low value for calcium sulphate corresponds to a smaller quantity of water; so the analyses in the set are comparable the one with the other.

In regard to the water remaining in the manufactured product, according to the best researches, this should correspond to the amount in the formula, $(CaSO_4)_2$, H_2O, or 6.2 per cent. Now, it actually happens that the per cent. of water calculated on the commercial product is usually higher than this, as nature makes the combination more carefully than man can dehydrate the material. For instance, a plaster containing 66.91 per cent. of calcium sulphate ought to have associated with it only 4.42 per cent. of water, but an analysis shows that there is really 6.41 per cent. In fact, even if the plaster is quite impure from containing quite large quantities of carbonates and of insoluble residue, the amount of water is hardly ever below four per cent.

NECESSITY OF A CAREFUL SAMPLING OF A DEPOSIT.

In the case of the deposits of gypsite, especially, the greatest difficulty is often experienced in getting an average sample of the bed. It is probable that the only way to get it accurately would be to take samples all over the surface, then at a stated depth beneath the surface, so as to get the composition at that depth, and again at another depth below the previous one, and so on to the bottom of the deposit. A sample taken one month will probably differ in composition from one taken the next month, as the workmen are farther down in the deposit. The necessity of careful sampling can be illustrated by a case in which specimens taken from the same prospect hole at different depths showed a range from about 41 per cent. to 70 per cent. of anhydrous calcium sulphate, with a corresponding increase in the amount of water. As the material is clay, or partially decomposed minerals, sand, and calcium and magnesium carbo-

nates in addition to the hydrated calcium sulphate, and from what we know of the methods of deposition, it naturally follows that there is a possibility of a great range of composition.

Some light may be thrown on the relative solubility of the beds of gypsite by the inspection of the analysis of a sample of water formerly used at one of the mills, and which had presumably leached through deposits of this material. In 1000 parts of the water the following constituents, probably united as here given, were found:

Silica and insoluble material	0.0136
Iron and aluminum oxides	0.0048
Calcium sulphate	1.9606
Sodium sulphate	0.0499
Magnesium carbonate	0.3001
Sodium carbonate	0.0473
Sodium chloride	0.0749
Total	2.4512

Comparing this with the gypsum deposits below, it will be noticed that the more soluble substances — sodium sulphate, sodium carbonate, and sodium chloride — are wanting in the mineral, though in some cases it is no doubt true that small quantities of alkaline salts remain undissolved by the water that has percolated through the bank.

Suppose this water is exposed to the air and gradually evaporates, it would deposit all its salts with their water of crystallization, but gradually this water would leave the efflorescent salts like sodium sulphate and sodium carbonate, so that eliminating this water the mass would have the composition:

Silica and insoluble residue	0.46 per cent.
Iron and aluminum oxides	0.18 "
Calcium sulphate, plus water ($CaSO_4+2H_2O$)	83.51 "
Sodium sulphate	1.63 "
Magnesium carbonate	10.11 "
Sodium carbonate	1.58 "
Sodium chloride	2.53 "
Total	100.

This mass when exposed to the action of water would soon loose its sodium sulphate, sodium carbonate, and sodium chloride, as these are the more soluble salts, and thus the per cent.

of the insoluble substances would be increased in the mass, and we should have a material much like the deposits that we find. Water saturated with calcium carbonate, also coming in contact with the mass would be liable to deposit some of that substance, and there might be an interchange of acid and base between the sodium carbonate and the calcium salts.

PLASTER OF PARIS AND CEMENT PLASTER AS THEY APPEAR ON THE MARKET.

The following analyses of some of the brands of these materials as they are offered for sale in open market may be of interest. None of these samples[90] was furnished by the manufacturers, or at their request. No. 1 is "Crystal Rock," manufactured by the Great Western Plaster Company, at Blue Rapids; No. 2 is "Roman," from Springdale, Barber county:

	No. 1.	No. 2.
Silica and insoluble residue	1.20	4.27
Iron and aluminum oxides	0.20	0.47
Calcium oxide	37.78	36.12
Magnesium oxide	0.56	0.70
Sulphuric anhydride	46.24	49.15
Carbonic anhydride (calculated)	1.36	2.12
Water	6.86	6.67

If combined, the results would probably be:

	No. 1.	No. 2.
Silica and insoluble residue	1.20	4.27
Iron and aluminum oxides	0.20	0.47
Magnesium carbonate	1.18	1.47
Calcium carbonate	1.68	3.07
Calcium sulphate	89.42	83.55
Water	6.82	6.67
Totals	100.50	99.50

In the following, No. 1 is "Acme"; No. 2 is "Sunshine," a finishing material manufactured by the Great Western Plaster Company, of Blue Rapids:

90. This and other analyses of this series were made by B. and McF.

	No. 1.	No. 2.
Silica and insoluble residue	12.04	0.97
Iron and aluminum oxides	1.50	0.30
Calcium oxide	34.27	37.07
Magnesium oxide	1.07	0.61
Sulphuric anhydride	42.20	52.93
Carbonic anhydride (calculated)	4.88	0.69
Water	4.80	7.29

Combining these amounts, and calculating the amount of carbonic anhydride probably present, the results would be:

	No. 1.	No. 2.
Silica and insoluble residue	12.04	0.97
Iron and aluminum oxides	1.50	0.30
Magnesium carbonate	2.24	1.28
Calcium carbonate	8.44	0.04
Calcium sulphate	71.74	89.98
Water	4.80	7.29
Totals	100.76	99.86

In the following, No. 3 is a cement plaster manufactured at Okarche, I. T., and No. 4 is a brand known as "Ivory," manufactured by the Blue Valley Plaster Company, and used especially for finishing:

	No. 3.	No. 4.
Silica and insoluble residue	13.29	0.85
Iron and aluminum oxides	0.71	0.16
Calcium oxide	33.00	38.03
Magnesium oxide	0.91	0.61
Sulphuric anhydride	43.34	53.57
Carbonic anhydride (calculated)	3.10	1.08
Water	5.78	6.33
Totals	100.13	100.63

If the above constituents are combined, the results would be as follows:

	No. 3.	No. 4.
Silica and insoluble residue	13.29	0.85
Iron and aluminum oxides	0.71	0.16
Magnesium carbonate	1.91	1.28
Calcium carbonate	4.77	0.94
Calcium sulphate	73.67	91.07
Water	5.78	6.33
Totals	100.13	100.63

Chemistry of the Manufacture of Plaster.

In making the plaster of Paris from gypsum, although the process is simply that of heating to drive off water, there are several points of importance to be considered in what seems a simple operation. It is stated that[91] "When gypsum is heated to about 120° to 130° it loses water, and is converted into burnt gypsum or plaster of Paris. This well known substance when mixed with water combines with it, evolving heat, and subsequently solidifies, taking the form of the vessel in which it is contained. It was formerly supposed that plaster consisted of anhydrous calcium sulphate, and that the setting was brought about by the direct combination of this with two molecules of water reforming gypsum, but the researches of Le Chatelier[92] have shown that the properly burnt plaster still contains about seven-eighths per cent. of water, and consists of the hydrate $2CaSO_4+H_2O$. When this is mixed with water, part of this hydrate, which is much more soluble than either the anhydrous salt or the hydrate with two molecules of water, dissolves in the water to form a saturated solution; it very soon, however, becomes converted into the hydrate $CaSO_4+2H_2O$, which, being less soluble, crystallizes out, thus allowing the water to dissolve more of the hemihydrate; the same process is then repeated until the whole of the hemihydrate is converted into gypsum. The latter separates into long thin prisms, which interlace to form the solid cake which remains.

"If the gypsum be heated too strongly in burning, it only takes up water very slowly, and is said to be dead-burnt; this is due to the whole of the water having been driven off, leaving anhydrous calcium sulphate. Such plaster when exposed to moist air takes up six-sevenths per cent. of water, and if mixed with water sets slowly, but with a normal hardness.

"An artificial calcium sulphate is now prepared by precipitating a solution of calcium chloride with dilute sulphuric acid, and sold under the name of pearl hardening or 'annaline.' It is used by paper-makers as a filling for writing paper."

91. A Treatise on Chemistry, Roscoe and Schorlemmer, new edition (1898), Vol. II, p. 438.
92. Ann. des Mines, 1887, 345.

In the process of manufacture, the details of which are given more fully in chapter VI, the iron kettles that are used hold about eight tons of material, and they are heated directly by means of a hot fire of coal beneath. The flame is carried around the sides by flues, with the object of heating all parts of the kettle. Although many devices have been suggested, such as heating by steam, and the use of kettles of peculiar construction, nothing has been found to be more practical than the kettles described (*loc. cit.*), in which the material is kept in motion by means of a mechanical stirrer making fifteen revolutions per minute. It is of the greatest importance that the partly calcined plaster shall not remain in contact with the heated iron, as in case very little water is left to be driven off the heat may become too intense, and disastrous results may follow. The heated material boils like thick cream, and runs almost like water.

The heat is kept constant, or nearly so, during charging, by letting the material drop in gradually, till a sufficient quantity is present, and then the boiling will increase in violence, so that it is occasionally thrown in "waves" out of the kettle. The boiling is, of course, due to the escape of the water of crystallization and the hygroscopic water that may be present. A short time before the process is completed (the whole process requires about three hours), there is a sudden settling down of the contents of the kettle, but soon the mass begins to boil again, and after a certain time, that can be quite accurately determined by the expert calciner, the charge is pronounced done, and, almost instantly, the kettle is opened at the bottom, and the finished product slips out into a storage vault. This operation also must be carried on very quickly and swiftly, as the fire is still burning under the kettle, and if there is no material to be heated, the bottom soon gets too hot. The second charge follows the first immediately. The calcined cement is then elevated to the top of the building and carried to a sifter, and the particles ("tailings") that are too large to pass through this are returned to the kettle and heated again.

The boiling material, on account of the steam given off, pro-

duces a considerable quantity of dust, which deposits all over the upper parts of the building, and on the vegetation near by. In some of the best mills this dust is collected and saved.

This process has been briefly described, in order to refer to some experiments that have been made on the composition of the plaster at different stages of its manufacture. Two complete sets of material from different plants have been secured, and analyses of these have been made. Samples taken April 4, 1897:

COMPOSITION OF PLASTER AT DIFFERENT STAGES OF MANUFACTURE.

	No. 1, crude.	No. 2, finished.	No. 3, dust.	No. 4, tailings.	No. 5, set.
Silica and insoluble residue	12.29	14.31	13.48	22.06	12.03
Iron and aluminum oxides	2.27	2.16	2.33	2.23	1.62
Calcium oxide	29.67	33.53	32.71	32.13	30.05
Magnesium oxide	0.78	0.91	0.59	0.56	0.61
Sulphuric anhydride	34.87	39.85	40.03	33.06	35.73
Carbon dioxide	3.52	4.11	2.87	5.35	3.55
Water	16.07	4.91	6.78	4.43	16.38
Totals	99.47	99.78	98.79	99.82	99.97

The most probable combination is as follows:

	No. 1, crude.	No. 2, finished.	No. 3, dust.	No. 4, tailings.	No. 5, set.
Silica and insoluble residue	12.29	14.31	13.38	22.02	12.03
Iron and aluminum oxides	2.27	2.16	2.33	2.23	1.62
Magnesium carbonate	.78	.91	.59	.56	.61
Calcium carbonate	8.01	9.42	6.53	12.17	8.07
Calcium oxide	2.12	1.85	2.56	4.70	1.89
Calcium sulphate	57.95	66.22	66.52	53.67	59.37
Water	16.07	4.91	6.78	4.43	16.38
Totals	99.49	99.78	98.79	99.78	99.97

In this case the determination of carbonic anhydride was carefully made in each sample, and it is interesting to notice that this confirms the opinion already expressed, that there is not enough carbon dioxide and sulphuric acid to unite with the bases present. In other words, the hydrochloric acid used to dissolve the mineral decomposes something besides the sulphates and carbonates, namely the silicates. If the iron is

present also as carbonate, as it frequently is in limestones, then the amount of free calcium and magnesium would be still higher.

If this series of determinations is analyzed, it is seen, first, in reference to the silica, that it increases in the finished sample about in proportion to the loss of water. In the dust, which contains more water than the finished sample, the amount of silica is, as would be expected, less. The tailings are made up of the hardest and most impure portion, and this portion would be expected to contain more silica; in fact it contains a very large amount. The set sample, since it contains about the same quantity of water as the original cement, would be expected to contain about as much silica, which it does. The calcium sulphate is highest in the dust, as though this represented the purest part of the material, which was blown off with the steam on account of its lower specific gravity. It is no doubt true that a partial separation of the siliceous material from the pure gypsum could be made by the process of winnowing, as it may be called. The tailings also contain more of the limestone than any of the other samples. In the light of these facts, it is doubtful whether there is any advantage in grinding and reheating the tailings, as they contain so much more silica and limestone than the average of the bed. Allusion has already been made to the varying amounts of water. That in the original sample is only 0.29 per cent. above the theoretical amount. After boiling it is 4.91 per cent., as compared with the theoretical amount, 4.38 per cent. This is an excellent agreement, when we consider that the work is done on a commercial scale and it is practically impossible to dehydrate every particle of the gypsite. When the plaster is set it takes up a sufficient quantity of water, so that there is only 0.31 per cent. more than in the original sample. This amount is only 0.22 per cent. above the theoretical amount. The material was partially dehydrated, losing three-fourths of its water, and then as soon as an opportunity was offered the crystals again formed with the original quantity of water, and the interlacing crystals made a firm, hard substance.

If in the process of heating the temperature was too high, some of the carbon dioxide would be driven off, as in the heating of limestone to make caustic lime, but the temperature is carefully regulated and not allowed to go above 400° F. It might seem that there would be a little overheating, but in the presence of the large quantity of water the temperature is kept down, and will be low as long as water is driven off. It should be remembered that about five per cent. of water still remains, and this would be driven off at a higher temperature or if the heating were continued beyond the critical period. So, till this last portion of water is expelled, the carbon dioxide will not be attacked. That this is practically true is shown by the series of analyses. The amount of carbon dioxide in the first sample was 3.52 per cent. and in the last 3.55 per cent.

Another complete set of analyses of the material, taken August 27, 1897, as it went through the mill, was made. The crude material at this plant was also gypsite. In this case the amount of carbon dioxide was not determined, but the results are from the calculated quantities. The samples selected were as follows:

No. 1, crude material.
No. 2, sample taken after two hours of boiling.
No. 3, the finished material.
No. 4, a sample that has been set.
No. 5, the screenings or tailings.
No. 6, a sample that has been treated with a "retarder."

The composition of each sample is as follows:

COMPOSITION OF PLASTER AT DIFFERENT STAGES OF MANUFACTURE.

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Silica and insoluble residue ...	9.78	10.84	12.02	10.84	25.83	11.63
Iron and aluminum oxides	0.30	0.50	0.44	0.42	1.52	0.67
Calcium oxide.....	30.16	33.69	36.21	30.53	29.62	35.24
Magnesium oxide.....	0.33	0.52	0.44	0.39	0.95	0.44
Sulphuric anhydride.....	38.18	40.62	40.21	35.20	22.99	40.94
Carbon dioxide (calculated)...	3.06	4.70	6.82	5.04	11.67	5.85
Water.....	17.37	9.02	4.98	16.35	4.18	4.78

These constituents are probably combined as follows:

	No. 1.	No. 2.	No. 3.	No. 4.	No. 5.	No. 6.
Silica and insoluble residue ...	9.78	10.84	12.02	10.84	25.83	11.63
Iron and aluminum oxides	0.30	0.50	0.44	0.42	1.52	0.67
Magnesium carbonate	0.70	1.10	0.93	0.82	2.00	0.93
Calcium carbonate.....	6.12	9.37	14.39	10.50	24.15	11.74
Calcium sulphate.....	64.91	69.06	68.36	59.84	39.08	69.60
Water.....	17.37	9.02	4.98	16.35	4.18	4.78
Totals.....	99.18	99.89	101.12	98.77	96.76	99.35

An examination of the second and third columns shows that 1.06 per cent. of water was driven off during the first two hours, and the remainder, 1.28, during the remaining time. This is about what would be expected, when it is remembered that some time is necessary to get the mass to a sufficiently high temperature so that the water begins to be eliminated rapidly. The remarks that were made in reference to the dehydration apply also here. If the theoretical amount of water in each sample is compared with the actual amount found, the results are as follows:

	No. 1.	No. 3.	No. 4.	No. 5.	No. 6.
Theoretical, from $CaSO_4$.....	17.67	4.52	16.29	2.58	4.60
Water found.....	17.37	4.98	16.35	4.18	4.78
Difference.....	0.30	0.46	0.06	1.60	0.18

There seems to be an excellent agreement in all cases except in the screenings. The difference in the case of the screenings was greatest in the other set of analyses. This is probably due to the fact that we have here other material present in so large a quantity that our supposition in regard to the combination of bases and acids is not correct.

The sample containing retarder should be compared with No. 3, and there seems to be a fair agreement here also. The quantity of the retarder that is added is so small it has not materially affected the composition.

Retarders and Accelerators.

Although much has been written in regard to the action of retarders, which are frequently used, especially in the purer grades of plaster, to defer the setting, the theory of their use seems to be a simple one. If, as has been assumed, the plaster sets because there are really a few small crystals that have not been dehydrated, and which "set the example," so to speak, to the other crystals to form, and if the strength of the set material is due to the mass of interlacing crystals, then any substance added to the water with which the calcined plaster is mixed, or to the dry plaster, which will keep the molecules apart, or from too close contact, will retard the setting. Such substances are dirt, or organic matter that is not of a crystalline character. Animal refuse, glue water, starch or bodies of the class known as "colloids" are thus used for this purpose, and wisely. Too much insoluble material or carbonates of the alkaline earths will of course dilute the plaster so that it will not set as quickly as a purer sample, and when it does set it will not be as strong, as there is not so much of it in a cubic foot; that is, there is not so much of a mass of interlacing crystals of hydrated calcium sulphate in a cubic foot as if it be pure. It is probable also that the use of organic retarders beyond a certain low limit will seriously reduce the strength of the set plaster.

On the other hand, it is a well known fact that a supersaturated solution of a salt, as for instance sodium sulphate, can be made, and immediately when a crystal of the salt is dropped into this solution the whole mass will crystallize. Crystals, or even solid particles of foreign material, will hasten the crystallization of the material. Apply the same reasoning to the setting of plaster, and in the light of known facts it is easy to see what will accelerate the setting. To make a good dental plaster, for instance, some other crystallizing salt, as alum or borax, is added, in small quantity to the plaster. The result of this is that after solution the added salt has a tendency to crystallize, and in so doing starts that process in the dehydrated gypsum. It is even

asserted that in using plaster of Paris it is essential that an old dish that has been previously used for mixing should not be used. It is evident that this is because some of the crystals of hydrated gypsum already formed would start the crystallization in the mass much sooner than it would otherwise begin.

Uses of Gypsum.

The uses of gypsum and its products may be divided into two classes:

Uses dependent on the weight, softness, fine texture, color, porosity or chemical composition, without burning.

As alabaster or satin spar, for making ornaments.

As a fertilizer, under the name of "land plaster."

For building purposes.

To weight fertilizers.

As an absorbent of organic material in fertilizers.

As an adulterant of foods and medicinal preparations, under the name of "terra alba."

In the manufacture of glass and porcelain.

Uses dependent on the absorption of water and "setting" of the material. Plaster of Paris, or partially dehydrated gypsum, is used:

As plastering for buildings.

As filling for fire-proof structures.

As molds for coins, statuary, pottery.

For the purpose of deodorizing foul air.

By surgeons, to hold broken limbs in place.

By dentists, to get an impression of the mouth.

For cornices, moldings, etc.

In alabastine and similar wall washes.

For making crayons.

In wines, to retard fermentation and prevent the formation of too much free acid.

In wines, to absorb water and strengthen the product.

Some Problems Proposed for Investigation.

In the practical working of the process of making plaster of Paris or cement plaster, there are numerous questions constantly arising in the mind of the thinking manufacturer, and the solution of many of these problems would improve the process of manufacture and render the product of more constant composition, so that the artisan could always calculate upon the behavior of the material under certain fixed conditions. This is of great importance, as in cases of unsatisfactory work there is always a tendency for the manufacturer to blame the man who uses the plaster for his wrong methods of use, and on the other hand for the artisan to assume that the material was not properly made. A few of these problems, upon which more light is needed, may be mentioned here.

What is the effect of sand or of other insoluble material upon the material made from the gypsite or from gypsum rock?

What is the effect of calcium carbonate upon the same material?

Is magnesium carbonate of any value in the material or is it detrimental?

What material can be best used to improve the quality and at the same time hasten the setting of plaster used for dental purposes?

Can any precautions be taken so that there shall not be a tendency to "streak," when pure white plaster is spread over a first coat of gypsite plaster?

Which is better, a fine or a coarse sample of plaster, when considered with reference to its sand-carrying quality?

Is any of the material, strictly speaking, hydraulic, and if so, what tends to increase this quality?

Is there any relation between the specific gravity and the strength or setting time of the material?

What is the best material to use as a "retarder," and what is its effect on the strength of the set plaster?

To answer these questions properly will require much time and many careful tests. These must be made in connection

with tests on the strength of the material, as is shown by its ability to withstand both tensile and crushing strains. Practical experiments should also be made, and the behavior of different classes of material when used upon the wall or in making of ornaments can be studied with advantage.

In conclusion, the author takes pleasure in acknowledging the special facilities placed at his disposal by the Acme Cement Plaster Company, the Dillon Cement Plaster Company, the Salina Cement Plaster Company, and other manufacturers and dealers, both in this state and elsewhere.

TABLE I.—Gypsum Production in the United States since 1889, by States.

STATES.	1889. (a)		1890. (a)		1891. (a)		1892. (a)		1893. (a)	
	Tons.	Value.	Tons.	Value.	Tons.	Value.	Tons.	Value.	Tons.	Value.
Kansas	17,332	$94,235	20,250	$72,457	40,217	$161,322	46,016	$195,197	43,631	$181,599
California	.....	.....	.....	.....	.....	.....	(d)	(d)	(d)	(d)
Colorado	7,700	28,940	4,520	22,050	.....	.....	(d)	(d)	(d)	(d)
Iowa	21,789	55,250	20,900	47,350	31,385	58,095	(d)	(d)	21,447	55,538
Michigan	131,767	373,740	74,877	192,099	79,700	223,725	139,557	306,527	124,590	303,921
New York	52,608	79,476	32,903	73,093	30,135	58,571	32,394	61,100	36,126	65,392
Ohio	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)	(d)
South Dakota	320	2,650	2,900	7,750	3,615	9,618	.....	.....	5,150	12,550
Virginia	6,833	20,396	6,350	20,782	5,959	22,574	6,991	28,207	7,014	24,359
Other states (c)	29,420	109,491	20,235	138,942	17,115	94,146	31,301	104,461	15,657	53,256
Totals	267,769	$764,118	182,995	$574,523	208,126	$628,051	256,259	$695,492	253,615	$696,615

STATES.	1894. (a)		1895. (b)		1896. (b)		1897. (b)		1898.	
	Tons.	Value.	Tons.	Value.	Tons.	Value.	Tons.	Value.	Tons.	Value.
Kansas	64,889	$301,884	71,852	$368,450	42,763	$199,563	50,045	$252,811	.....	.....
California	(d)	(d)	5,158	51,014	1,310	12,580	2,200	19,250	.....	.....
Colorado	(d)	(d)	.....	.....	.....	.....	.....	.....	.....	.....
Iowa	17,906	44,700	18,600	43,710	18,631	34,020	65,000	195,000	.....	.....
Michigan	79,958	189,620	80,601	174,067	56,000	112,000	48,500	97,000	.....	.....
New York	31,798	60,262	29,176	50,806	22,923	39,771	22,885	40,253	.....	.....
Ohio	20,827	69,597	33,443	101,365	21,341	45,142	16,300	33,800	.....	.....
South Dakota	4,295	16,050	6,400	20,600	6,260	19,080	4,800	14,900	.....	.....
Texas	6,925	27,300	5,670	32,045	7,972	37,229	13,729	61,780	.....	.....
Virginia	8,106	24,431	8,515	32,068	5,444	18,210	5,207	13,812	.....	.....
Other states (c)	4,608	27,875	2,265	18,120	12,889	65,541	13,195	91,071	.....	.....
Totals	239,312	$761,719	261,685	$892,245	195,553	$583,186	241,861	$774,626	.....	.....

Production is stated in short tons of 2000 pounds.

(a) Statistics from Eighteenth Annual Report U. S. Geological Survey, Part V, p. 1267.

(b) Statistics from Mineral Industry, Scientific Publishing Company, New York, except for Kansas in 1897, where statistics are from Mineral Resources of Kansas, published by this Survey.

(c) "Other states" includes Indian Territory, Missouri since 1894, Utah, and Wyoming, in each of which reports come from only one company.

(d) Included in "other states."

TABLE II.—Gypsum Imported into the United States.

Year.	Calcined.		Not calcined.		Plaster of Paris.	Total value.
	Tons.	Value.	Tons.	Value.		
1867 (*a*)	.....	$29,895	97,951	$95,386	.....	$125,182
1868	.....	33,988	87,694	80,362	.....	114,350
1869	.....	52,238	137,039	133,430	844	186,512
1870	.....	46,672	107,237	100,416	1,432	148,720
1871	.....	64,465	100,400	88,256	1,292	154,013
1872	.....	66,418	95,339	99,902	2,553	168,873
1873	.....	35,628	118,926	122,495	7,336	165,459
1874	.....	36,410	123,717	130,172	4,319	170,901
1875	.....	52,155	93,772	115,664	3,277	171,096
1876	.....	47,588	139,713	127,084	4,398	179,070
1877	.....	49,445	97,656	105,629	7,843	162,917
1878	.....	33,496	89,239	100,102	6,989	140,587
1879	.....	18,339	96,963	99,027	8,176	125,542
1880	.....	17,074	120,327	120,642	12,693	150,409
1881	.....	24,915	128,607	128,107	18,702	171,724
1882	5,737	53,478	128,382	127,067	20,377	200,922
1883	4,291	44,118	157,851	152,982	21,869	218,969
1884	4,996	42,904	166,310	168,000	.....	210,904
1885	6,418	54,208	117,161	119,544	.....	173,752
1886	5,911	37,642	122,270	115,696	.....	153,338
1887	4,814	37,736	146,708	162,154	.....	195,890
1888 (*b*)	3,393	20,764	159,204	170,023	.....	190,787
1889	5,554	40,291	173,701	179,849	.....	220,140
1890	7,689	55,250	174,030	174,609	.....	229,859
1891	9,713	97,316	112,021	129,003	.....	226,319
1892	6,992	75,608	184,002	232,403	.....	308,011
1893	3,996	40,959	166,929	180,263	.....	221,222
1894	2,059	16,823	165,100	179,237	.....	196,060
1895	3,348	21,526	195,630	215,705	10,352	247,583
1896	3,348	22,058	183,165	193,549	.....	215,607
1897	185,406	140,494	48,178	50,981	.....	191,475

(*a*) Statistics from 1867 to 1887, inclusive, are from Eighteenth Annual Report U. S. Geological Survey, Part V, p. 1268.

(*b*) Statistics from 1888 to 1897, inclusive, are from The Mineral Industry, Scientific Publishing Company, New York.

Product is given in long tons of 2240 pounds.

TABLE III.- Production of Gypsum in United States, by Years.

Year.	Product (short tons).	Value.	Year.	Product (short tons).	Value.
1880 (*a*)	90,000	$400,000	1889	267,769	$764,118
1881	85,000	350,000	1890	182,995	574,523
1882	100,000	450,000	1891	208,126	628,051
1883	90,000	420,000	1892	256,259	295,492
1884	90,000	390,000	1893	253,615	696,615
1885	90,405	405,000	1894	239,312	761,719
1886	95,250	428,625	1895 (*b*)	261,635	892,245
1887	95,000	425,000	1896	195,553	583,136
1888	110,000	550,000	1897	241,861	774,626

(*a*) Statistics from 1880 to 1894, inclusive, are from the Eighteenth Annual Report U. S. Geological Survey, Part V, p. 1267.

(*b*) Statistics for 1895, 1896, and 1897 are from The Mineral Industry, Scientific Publishing Company, New York.

TABLE IV.— Graphic Outline of Gypsum Production of Kansas.

TONNAGE.

VALUE.

CHAPTER X.

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ADDENDA.

SINCE the report on gypsum was placed in type, a new industry has come to the notice of the writer.

Four miles west of Sun City, in Barber county, and in the Medicine Lodge gypsum area, was located the mill of the Standard Cement Plaster Company. This mill was built on the north side of the Medicine Lodge river, overlooking one of the most beautiful valleys in the state. The mill was used for some time, and manufactured a good quality of white finish plaster, from the gypsum rock. The property finally became involved in court trials and was closed, as stated in the foregoing report. During the last few months the mill and ground have changed hands, and are now under the control of the Roman Cement Plaster Company, with offices at Kansas City, Mo.

A geological section back of the mill shows twenty feet of solid gypsum rock, resting on a limestone floor. The solid rock is covered by four feet of snow white porous gypsum with a fibrous structure, the fibers being vertical. On account of the porous character of the rock, it is very light in weight, and is readily quarried. Over this gypsum is found from eight inches to five feet of red clay impregnated with gypsum, and the surface layers are filled with grass roots. Formerly this surface red material and altered gypsum were removed and only the solid rock used for plaster.

When Mr. Jno. Bickel took charge of the plant for the Roman Cement Plaster Company, he conceived the idea of trying this surface gypsum and reached good results. At the present time these surface deposits are used, and they make a plaster with a natural red or terra cotta color which is attractive and popular.

In a recent trip to this region, I find that material similar to that on top of the hills over the solid gypsum rock occurs also in the valleys, forming deposits which are about 30 or 40 feet thick over a considerable area. In many places the thickness of material whose value has not yet been determined would reach 150 feet.

In origin, these deposits are apparently quite different from the gypsum earth deposits farther north. They are not in low ground and springs of water are not connected with them; yet at the same time they have resulted from water action subsequent to the original deposition from the old seas, and they are recent secondary deposits.

The gypsum has weathered first into the fibrous blocks, and these have further changed to granular gypsum, associated with red clay which has washed or blown in from the adjacent hillsides. The result has been to form an earth deposit filled with gypsum and organic matter, the latter producing a slower set and acting as a natural retarder. Under the microscope this material is beautifully crystalline, the crystals showing even under a low-power glass.

I regret that we cannot submit analyses of these materials, which would no doubt throw important light upon their origin and value, but these are not yet completed. An analysis of the finished plaster appears on pages 119 and 159. This analysis shows the percentage of silica is low and sulphate of lime (gypsum) is high, as compared with other gypsum earth plasters. The red color of the original material and finished plaster is no doubt due to iron, though the analysis shows the percentage is very low, in fact lower than many of the whiter plasters.

Nature in this area has apparently been working on a large scale, in a manner somewhat similar to that in other gypsum earth areas. Some tests made on this material show that it makes a very hard plaster, and it is spoken of with favor by those who have actually used the plaster in buildings at Kansas City.

The mill of this company is located about six and one-half miles from the Englewood branch of the Atchison, Topeka & Santa Fe railway. If a superior quality of cement plaster can be made from this material, the upper Medicine Lodge valley will become one of our important plaster districts. The property is managed and controlled by very able business men; and, on account of the peculiar nature of the deposit, its future will be watched with much interest.

G. P. G.

MAY 8, 1899.

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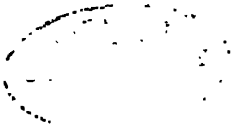
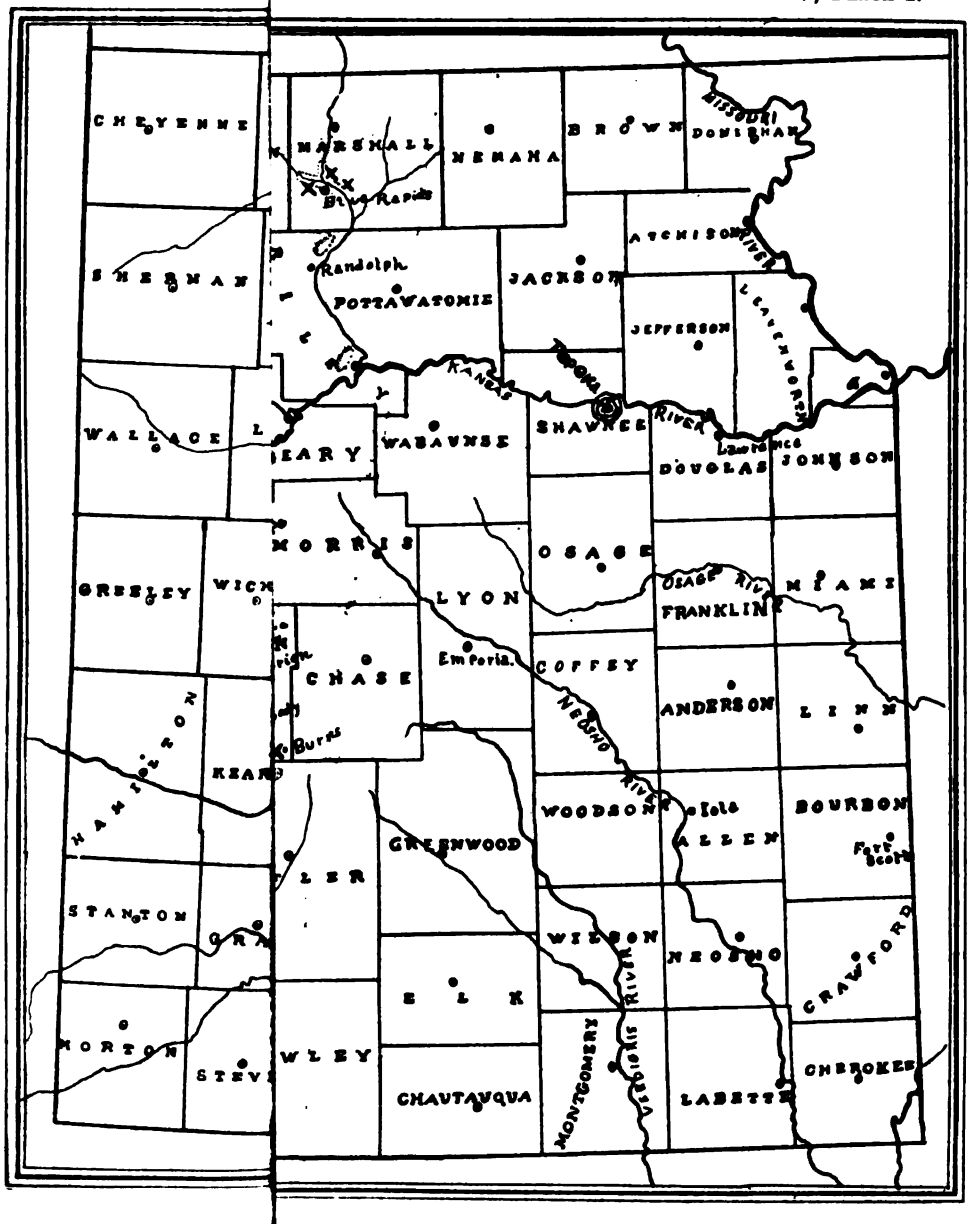
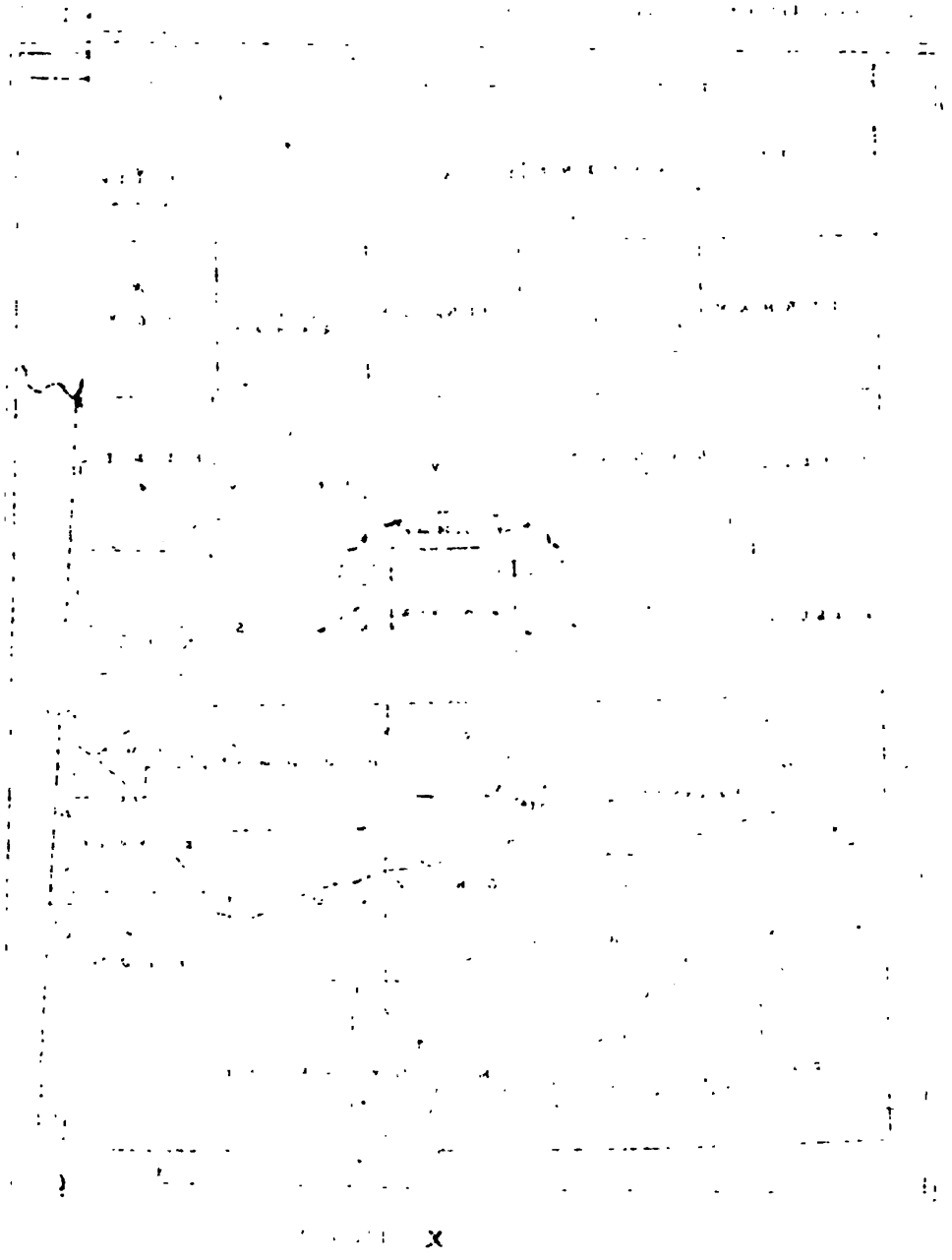
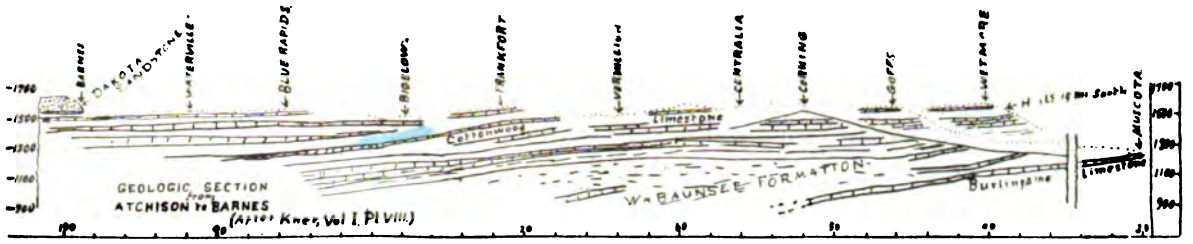
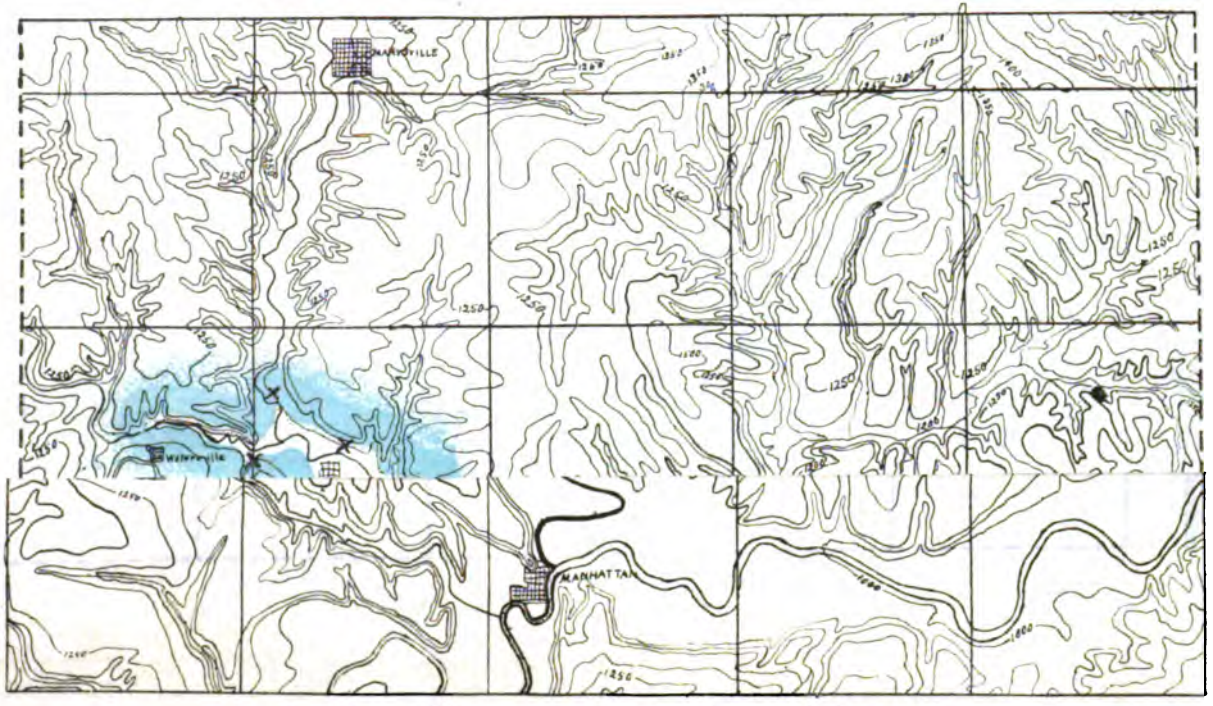




= Gypsum Earth Deposit.

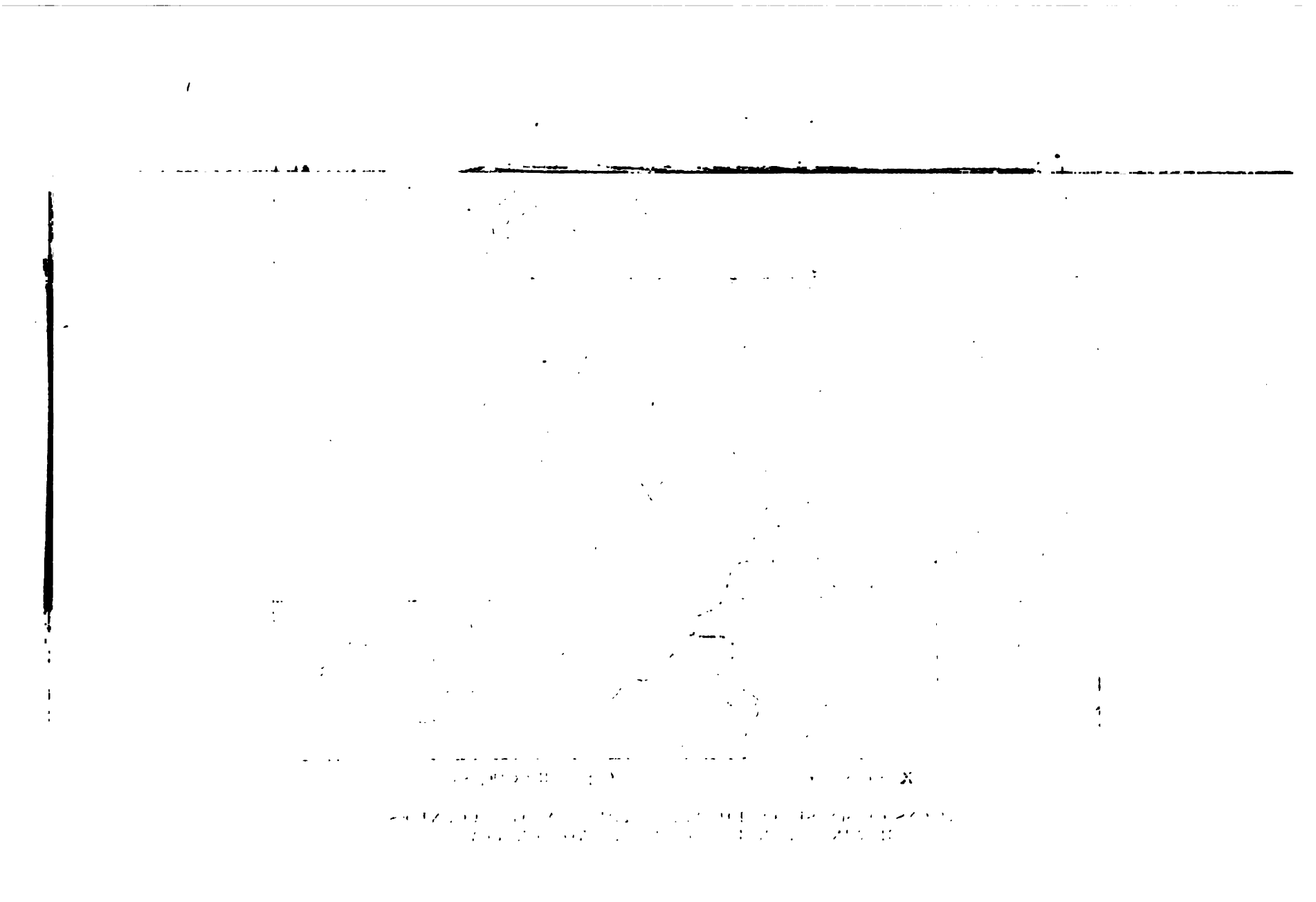


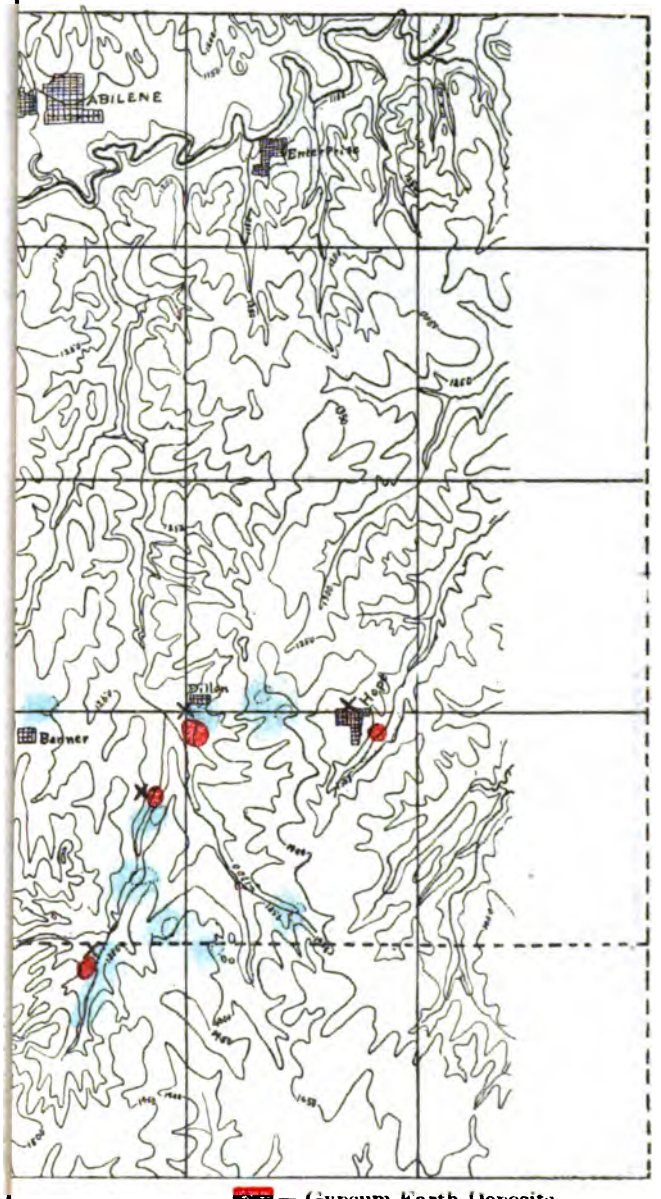




X = Plaster Mills. . = Gypsum Rock Deposits.

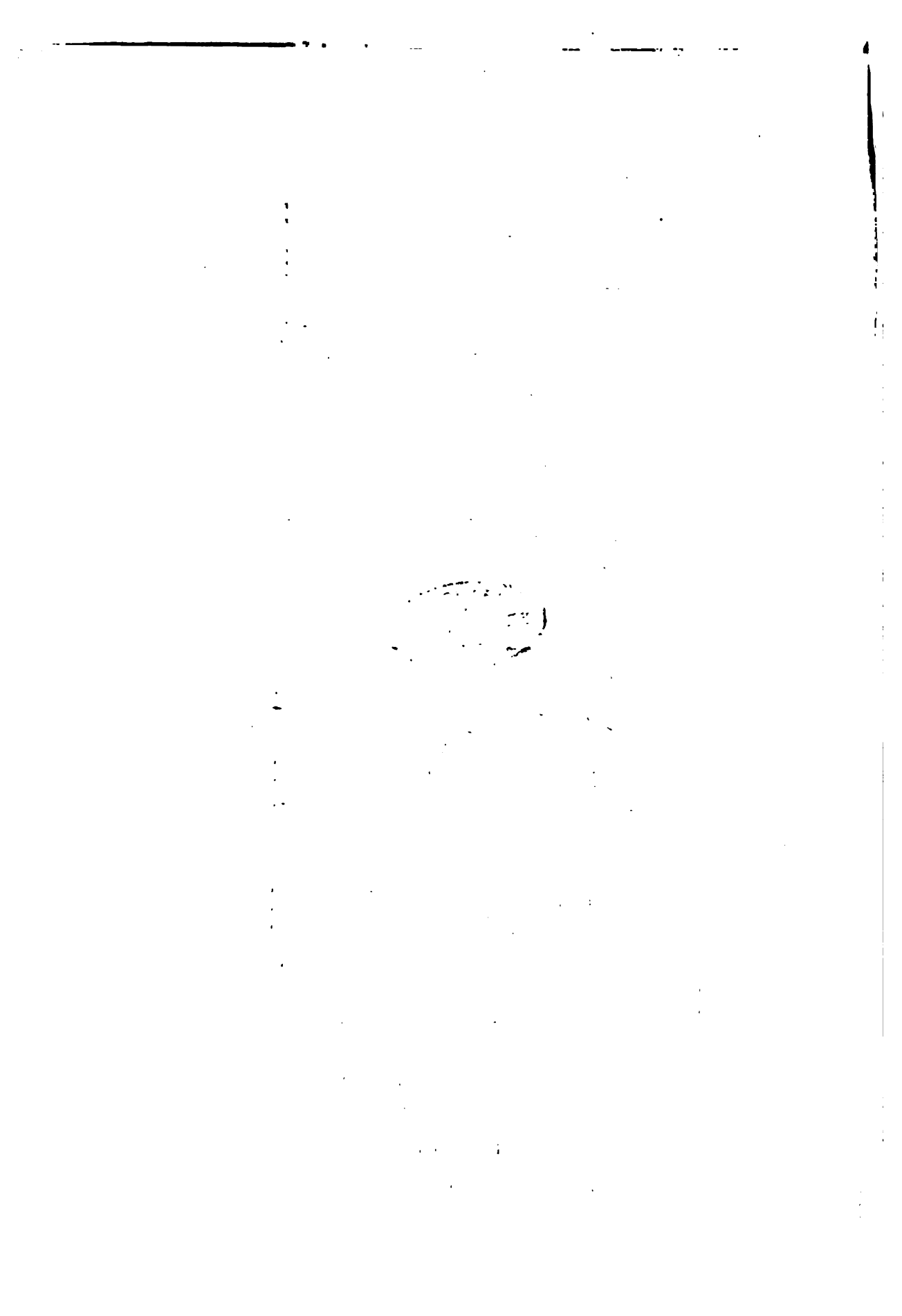
PORTIONS OF MARSHALL, RILEY, AND POTTAWATOMIE COUNTIES, SHOWING GYPSUM DEPOSITS AND TOPOGRAPHY.

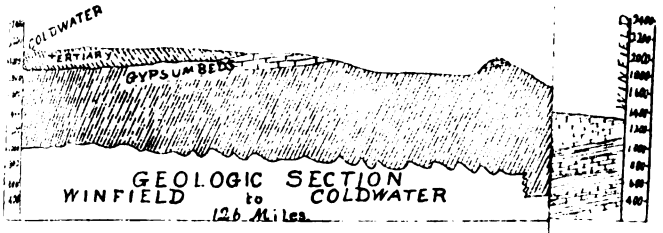


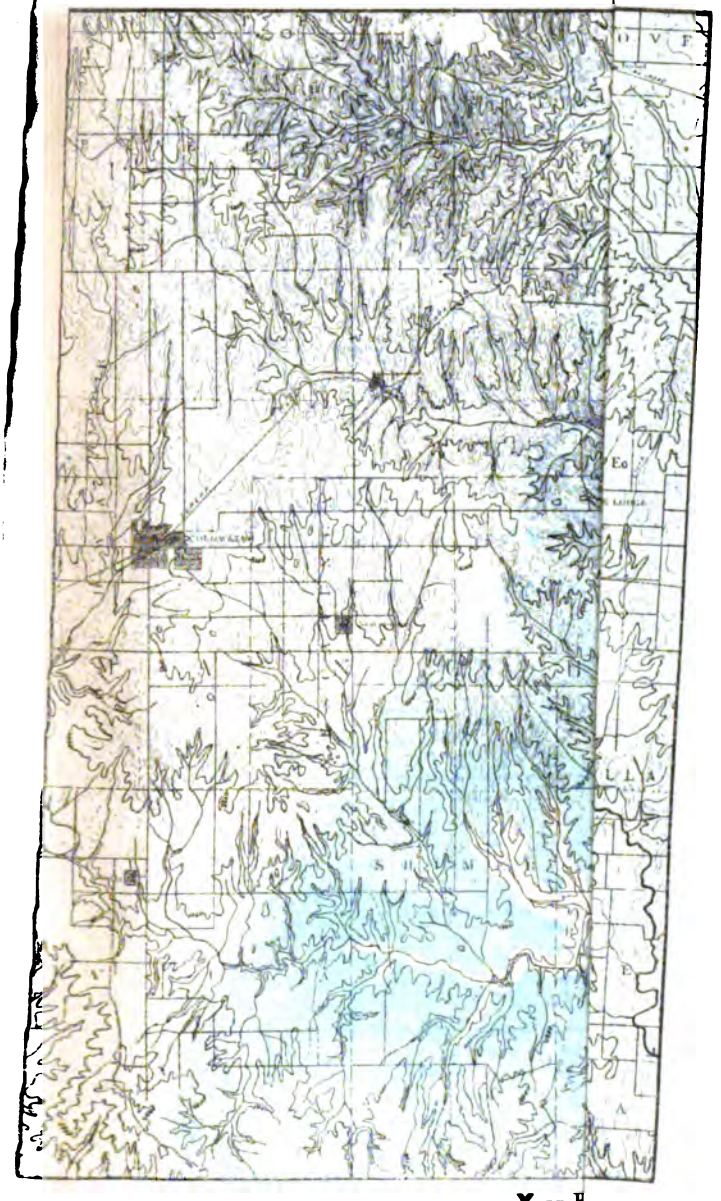


= Gypsum Earth Deposits.

GYPSUM DEPOSITS AND TOPOGRAPHY.

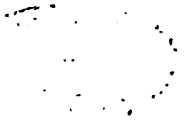






X = E

PORTIONS OF BARBER, COMANC



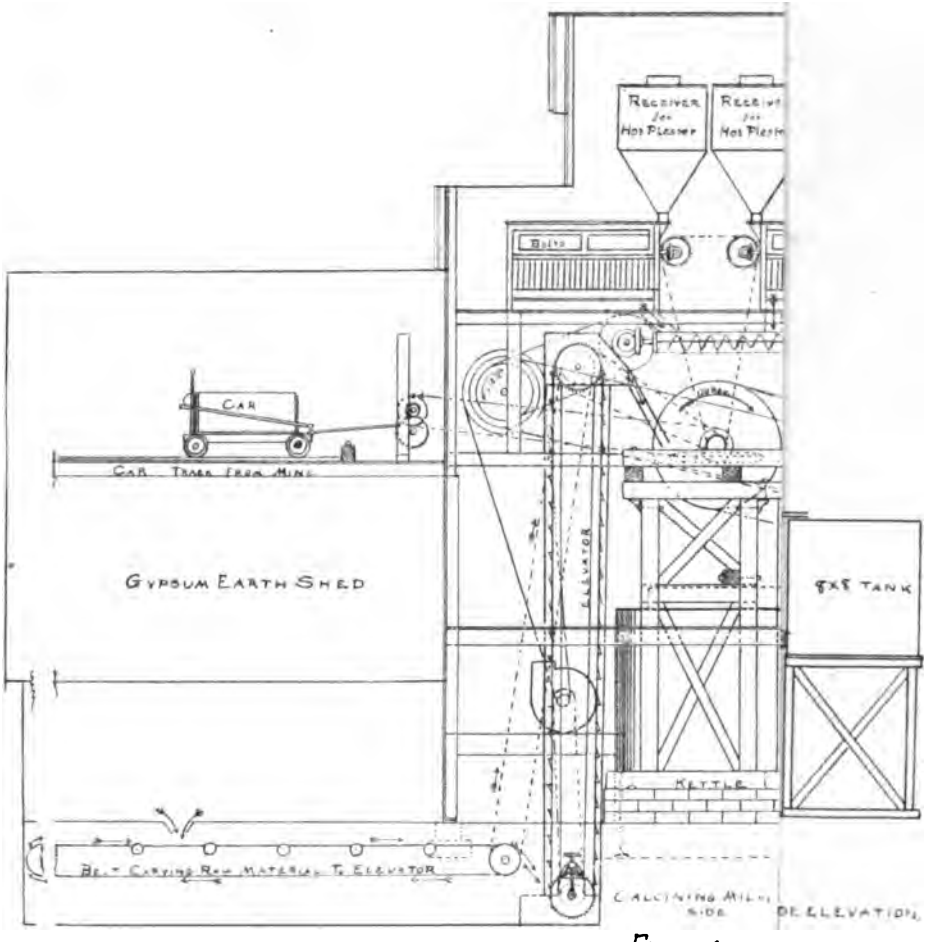


Figure 1

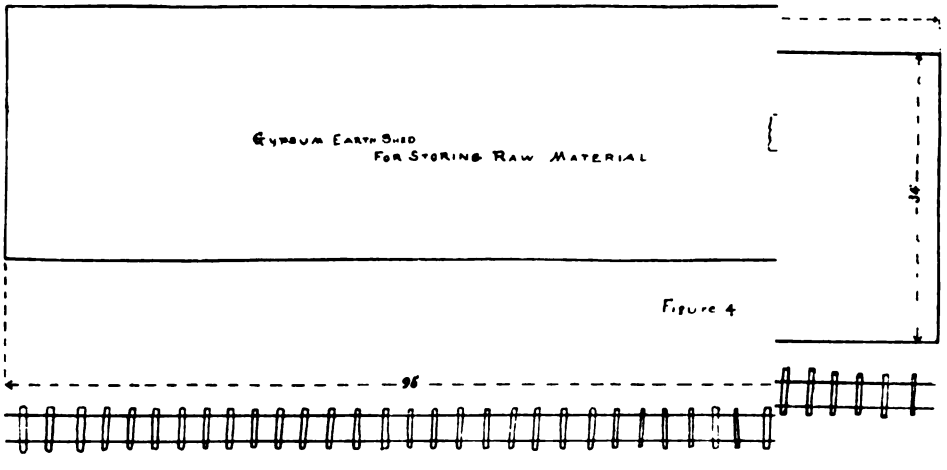
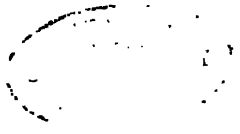
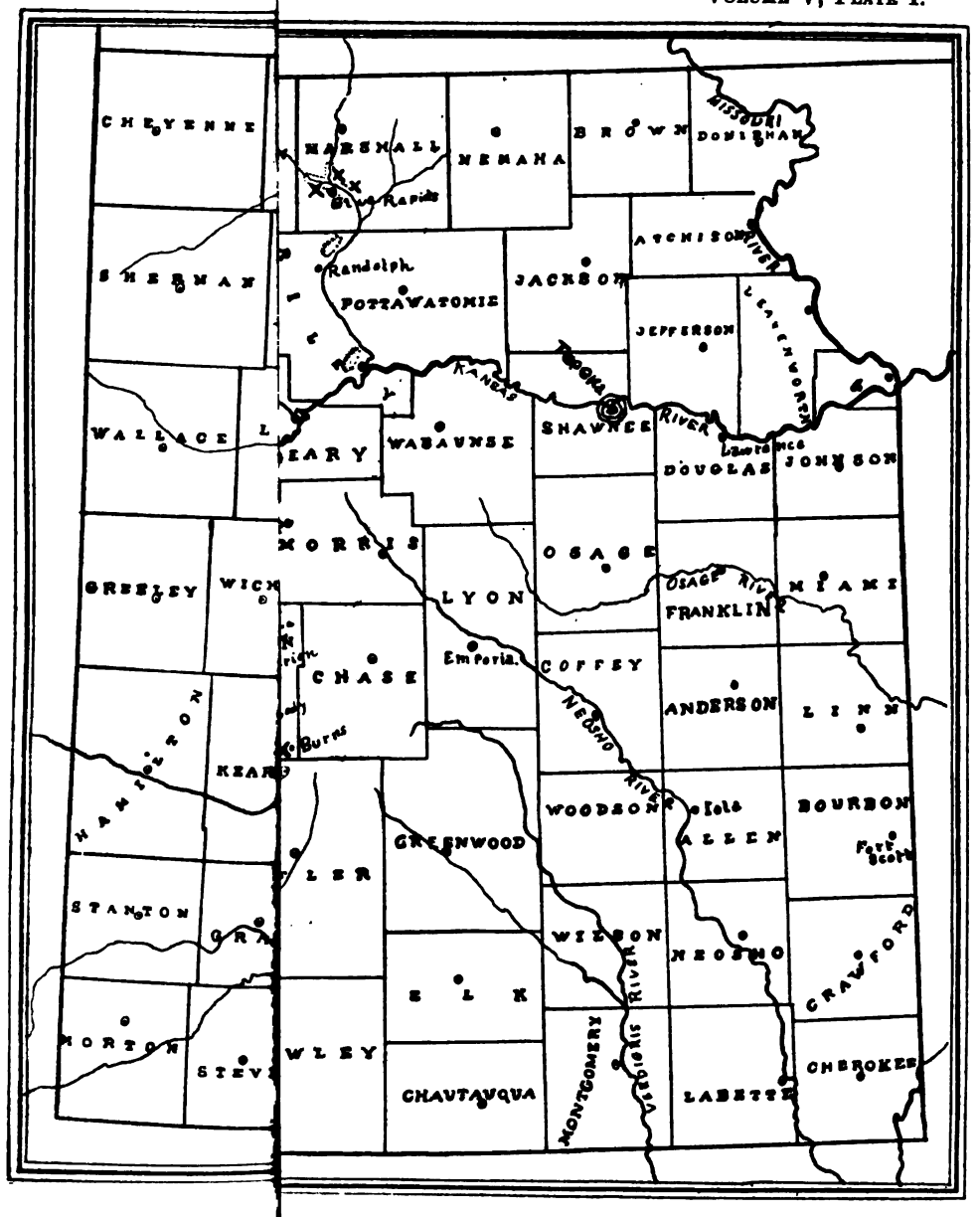


Figure 4

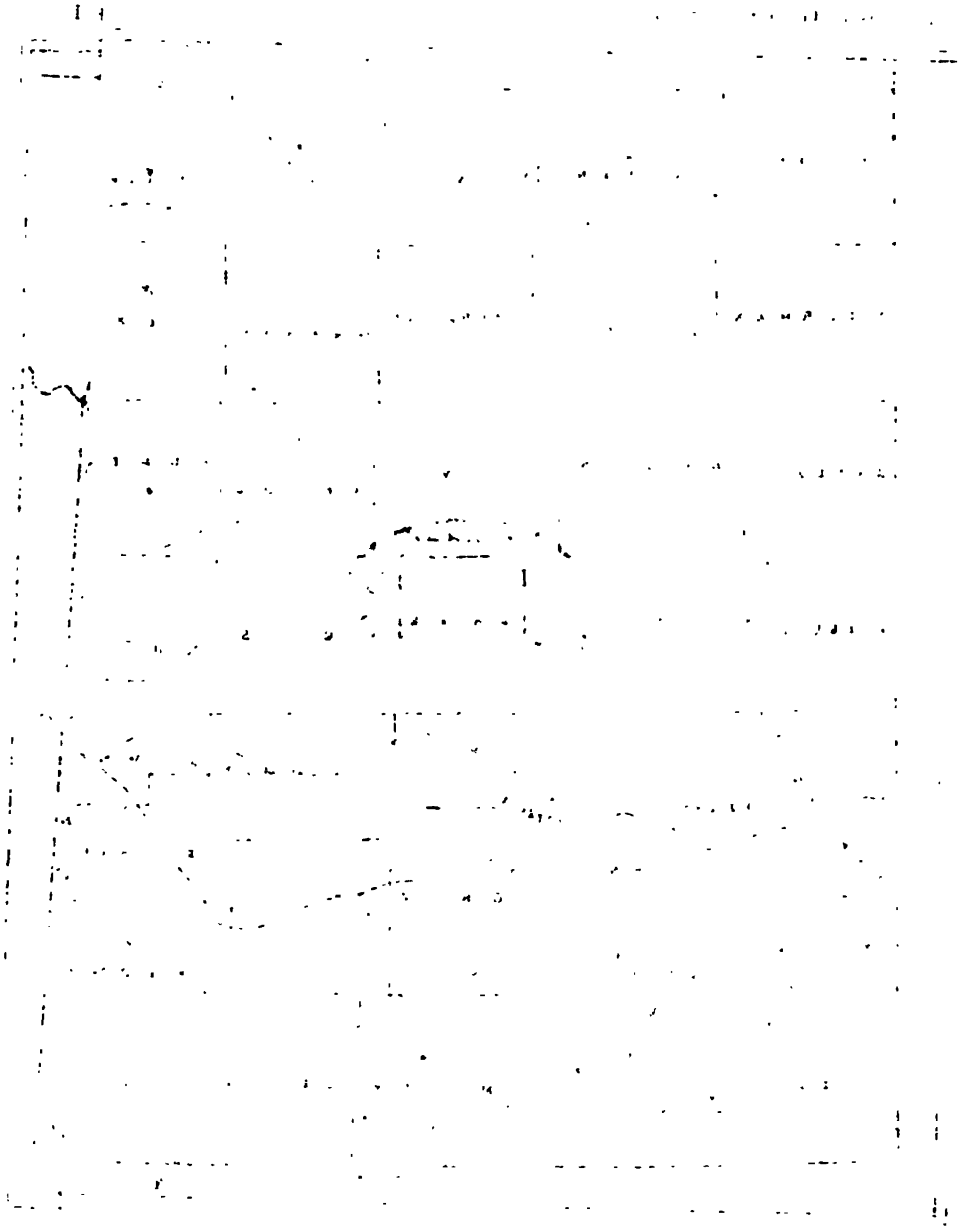
Figure 1.—Calcining Mill, east side elevat
Figure 2.—Calcining Mill, north end eleva
Figure 3.—Power House, east side elevati

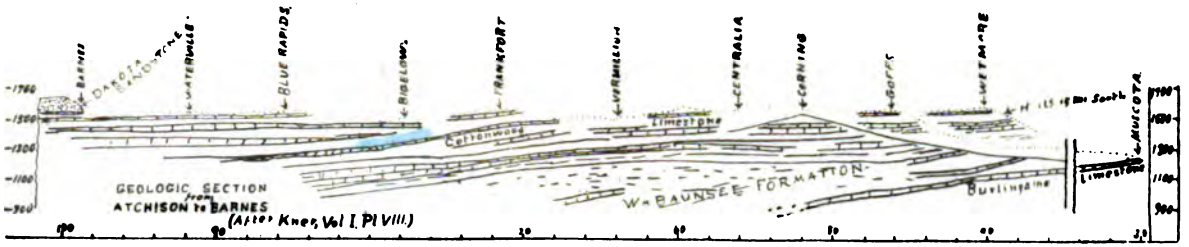


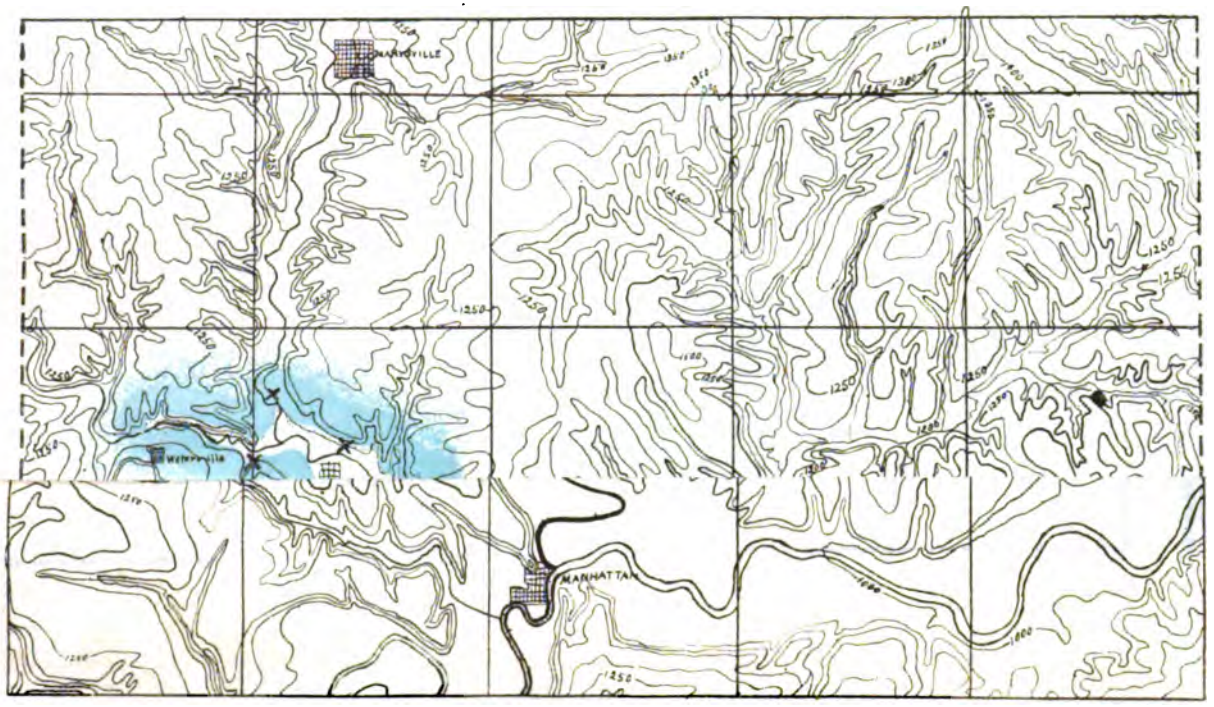
University Geological



= Gypsum Earth Deposit.







X = Plaster Mills. **= Gypsum Rock Deposits.**

PORTIONS OF MARSHALL, RILEY, AND POTTAWATOMIE COUNTIES, SHOWING GYPSUM DEPOSITS AND TOPOGRAPHY.